12. ICHTHYOLITH BIOSTRATIGRAPHY OF WESTERN NORTH PACIFIC PELAGIC CLAYS, DEEP SEA DRILLING PROJECT LEG 86[1]

P. S. Doyle and W. R. Riedel, Scripps Institution of Oceanography[2]

ABSTRACT

Pelagic clay sequences representing most of the Cenozoic Era were cored at Sites 576 and 578; the three holes drilled at Site 576 penetrated to Cretaceous sediments. A Cretaceous-Paleogene succession was obtained from Hole 577. The combined results from these holes, and some piston cores from more eastern localities, provide the basis for a synthesis of North Pacific Cenozoic ichthyolith stratigraphy. The synthesis is approached both by conventional biostratigraphic procedures and by a probabilistic interpretation based on events weighted according to their relative reliabilities. Seven new taxa from the Paleocene are described, thus improving the stratigraphic resolution attainable in that epoch.

INTRODUCTION

On Leg 86, ichthyoliths were investigated at four sites:

Site 576: 32°21.36′N, 164°16.54′E; water depth 6217 m,

Site 577: 32°26.51′N, 157°43.40′E; water depth 2675 m,

Site 578: 33°55.56′N, 151°37.74′E; water depth 6010 m, and

Site 581: 43°55.62′N, 159°47.76′E; water depth 5476 m.

Additional information on late Paleogene and Neogene ichthyolith successions, required for probabilistic stratigraphic interpretations, is shown in Table 1 based on the following MPGII piston core samples provided by G. R. Heath of Oregon State University, Corvallis:

Y74-3-62PC: 33°8.7′N, 151°15.8′W; water depth 5329 m,

Y74-3-65PC: 33°13.2′N, 150°59.6′W; water depth 5512 m, and

Y74-3-73PC: 33°26.6′N, 150°54.7′W; water depth 5540 m.

Figure 1 shows the locations of these sites, and of other Pacific sites from which we obtained samples contributing to ichthyolith stratigraphic interpretations.

In addition to providing a time-stratigraphic interpretation of the Leg 86 cores, we improved our understanding of Paleocene ichthyolith stratigraphy (describing seven new subtypes) and continued development of a procedure for probabilistic stratigraphic interpretations by employing a method of indexing the reliability of biostratigraphic events as applied in Gottfried et al. (1984).

Sediment samples treated were of approximately 40 cm^3 from Deep Sea Drilling Project (DSDP) Holes 576, 576B, 577, 578, and 581, of 100 cm^3 from Hole 576A, and of 150 cm^3 from the MPGII cores. Sample and slide preparation techniques followed those detailed by Edgerton et al. (1977). The numbers of ichthyoliths in the fractions coarser than 63 μm commonly ranged from 100 to several thousand per sample. Forms useful for stratigraphic interpretations at present constitute only a very small fraction of the total. Numbers of specimens observed are shown in Tables 1–4.

CONVENTIONAL STRATIGRAPHIC INTERPRETATIONS

Over the past 10 yr., we have built up an ichthyolith stratigraphy by establishing the ranges of approximately 120 taxa (*subtypes*) in sediment sequences in which ages have been determined on the basis of other groups of microfossils, mainly calcareous nannoplankton (Doyle et al., 1974; Dunsworth et al., 1975; Doyle et al., 1977; Gottfried et al., 1985). Application of this ichthyolith stratigraphy to pelagic clay sequences results in age assignments to about the level of epochs within the Cenozoic (Edgerton et al., 1977; Doyle and Riedel, 1979b; Kaneps et al., 1981). These "conventional" procedures are here applied to the Leg 86 sequences, with the results summarized below and shown in the left-hand columns of Tables 2–4.

As the basis for stratigraphic comparisons, we have used only Pacific Ocean samples with ages assigned on the basis of calcareous nannofossils or radiolarians and not Atlantic and Indian Ocean samples (which were taken into account in our earlier correlations—Doyle and Riedel, 1979a). Until sufficient ichthyolith data are accumulated to allow formal zonal definitions, we do not capitalize subepoch designations assigned on the basis of these microfossils. Site 577 is not discussed in the following paragraphs because its stratigraphic interpretation is based on calcareous nannofossils.

Hole 576

Standard samples 40 cm^3 in size were taken from cores in this hole. Concentrations of ichthyoliths and dry weights of samples are given in the right-hand columns of Table 2.

Ichthyoliths in Cores 2 through 4 are late Miocene or younger, based on the presence of *Long ellipse, Narrow*

[1] Heath, G. R., Burckle, L. H., et al., *Init. Repts. DSDP*, 86: Washington (U.S. Govt. Printing Office).

[2] Address: Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093.

Table 1. Numbers of observed specimens of taxa in samples from the central North Pacific MPG-II area.

Samples	Subtypes / Depth (cm)	Five peaks flared base	Triangle pointed margin ends	Triangle inline halfway	Triangle with triangular projection	Flexed triangle shallow inbase	Triangle concave base	Triangle medium wing	Wide triangle	Triangle short wing	Triangle broad wing	Triangle transverse line across	Narrow triangle cross-hachured	Tanged triangle	Triangle one canal above	Broad triangle parallel inline	Wide triangle straight inbase	Triangle hooked margin	Narrow triangle straight inbase	Triangle double flex	Triangle sigmoid	Small dendritic few radiating lines	Triangle with parallel inline	Pointed triangle short inline	Triangle with canals	Pointed triangle long margins	Curved triangle inline constricted	Rounded apex triangle	Flexed triangle shallow inbase ≥120	Triangle with base angle	Asymmetrical peak depression	Triangle with high inline apex	Small circular center	Triangle inward angle	Small dendritic many radiating lines	Large with numerous lines	Rectangular saw-toothed	Two triangles	Short triangle stepped margin	Curved triangle pointed margin	Elliptical with line across	Small triangle long striations	Circular with line across	Short rectangular with striations	Long rectangular with striations	Triangle sinuous inline	Stippled triangle	Long triangle short inline	Long ellipse	Triangle concave first margin	Long triangle stepped margin	Narrow triangle ragged base	Triangle irregular base
Y74-3-62PC	40–60																	4								3		2				3				1	1	1	1	1	7	23	7		1				4	6		3	2
	140–160																	5										2			1	2					2	1		1	21	23			1	1		5	4	3		5	1
	240–260				1											2		2								3		3		1						1	13	1			4	2						9			2		
	310–330		1	1	5	12		6	1	4		1				13		7	2		2	8	4	3		1		8	1	4	1	7			2	4	11	3	1	3	1	11	1					cf					
	380–400			1	20	14		4		4						6		3	4		1	4	2			2		3				1	1		3	1	7			2													
	470–490			1	5	13		3		2		3				5	1		1				1			2		1	1	4				?	2	1				2													
	570–590		1		11	3		3		2		15		1	4	15	2	1	1		1				1			1	3	2	2	1		1																			
	660–680		13		51	1	1	12		9		23	1	2	?	4	8	2	2		8				3	1		1							1		?																
	760–780		6	1	23	1	2	4		2		12	4	3		1		2	1																																		
	860–880		11		17		2	11		2		8	2	2				2	2																																		
	960–980		44		46		4	9		2		5				1																																					
Y74-3-65PC	40–60																									1		1				3							2	2	17	14		2	1				6	7		1	8
	140–160				1													1								2		3				10				1			3	2	48	30		4	4	1		3	14		4	1	
	240–260															2		1				1				4		5		1		6	1			1	16	1	1	2	3	2			1	2		9			1		
	340–360		9	1						7		1	1			7	1	5	1		1	4				2		10		1	1	2			1		5	1	1	2	1	2				1		6			1		
	410–430				15	16		2		9					2			3	4	2		10	2			4		2	1	9					2	15	1	2	3			2						?					
	490–510			4	14	12		2							2	1		1	4				3			5		3	4	1		20			8	12	3																
	600–620			1	18	6		3		1		15				4		3	2				4	1						1					3	1	1																
	720–740		1	2	29	1		3	1			6	1		2	4		4	1	1					2	1			1								2			?													
	830–850		5		22	1		18		3		19	2			1			1					3											1	?																	
	930–950		7		16		2	7	1	1		2	1					2	2					1	1																												
	1020–1040		5		3			5				2		1		1																																					
Y74-3-73PC	100–120				1			1								2		2	1							1		4				7			1	1					18	19	6		1				16	3		1	5
	200–220																									1		4				4					6			1	9	7	6	2	1	1		6	2				
	310–330							1				1						1				1				1		1		1		1				1	2	1	1	1	3	3				1	1				1		
	400–420				7			1		4		1				7	2	3	1	3			1			4		3		3	2	3	1		5	3	5		4	2		3		1				1					
	485–505		1		9	2		6		3		3				5		3			1	11				9		4		5		9	1		1	5	1			1		2											1
	650–670		1		26	8	1	8		1		10				18		2	3			1	2				1	5		6		1				1	1																
	737–752				10	11		3		3		1	6												2			13		?	1		1							1													
	775–795		1		6	15		4	1			11			1	9	1	2	1					5	1	1		3	2		1		1							1													
	880–900		6		15	1		17				4				5		2	3		4	2										cf	1				1																
	980–1000		2		19			13	2	1		6		3		3			2	1	6				1			1							1																		
	1080–1100	1	4		10	1	1	19				4		2	1	1	1		2		1						1							1																			
	1180–1200	3	6		7	1	1	18	1	6		2	1	2	2	5	2	2	2						6							cf																					
	1204–1219	1	27		29	2	2	7			1		43						1	1																																	

Note: The total number of ichthyoliths in each sample ranges from several hundred to several thousand.

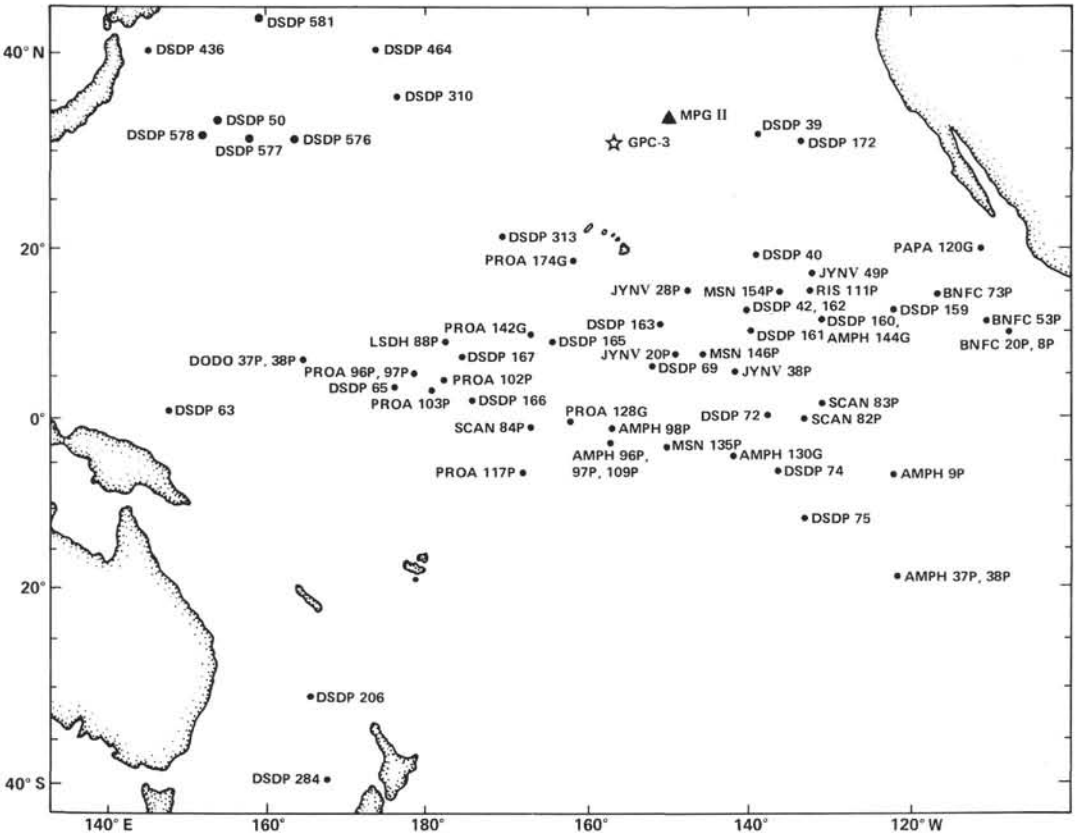

Figure 1. Location of sites from which samples were used in this study. In pelagic clay sequences from Deep Sea Drilling Project (DSDP) Sites 576, 578, and 581; GPC-3, and the MPG-2 area (location of piston cores Y74-3-62-PC, Y74-3-65PC, Y74-3-73PC) ichthyoliths are the only microfossils available for biostratigraphic control. Samples from the other sites contain both ichthyoliths and other microfossils, permitting intercorrelation of biostratigraphies.

triangle ragged base, and *Long triangle stepped margin*. Although the Miocene/Pliocene boundary cannot yet be distinguished on the basis of ichthyolith events in samples dated by other microfossils, the concurrence of the beginning of the range of *Long ellipse* and the end of the range of *Long triangle short inline* in Core 5, Section 6 indicates a late Miocene age. The ranges of these two taxa consistently overlap at discrete levels and in approximately the same position in relationship to the distribution of the other taxa in the Neogene sections from Holes 576, 576A, and 578, the three cores from the MPGII area, and GPC-3. This co-occurrence is at 6.50 m in GPC-3. Paleomagnetic stratigraphy indicates an age of 2.4 m.y. (Gilsa-Matuyama/Gauss boundary) at 4.5 m (Corliss et al., 1982, p. 284). At Site 578, these two taxa appear together below sediments with late Miocene radiolarians and diatoms (Table 3).

Core 6, Section 3 is Oligocene, based on the presence of *Rounded apex triangle* and *Flexed triangle shallow inbase ≥120*, and the absence of *Small triangle long striations* which is commonly found in the Neogene (Kaneps et al., 1981, p. 329).

Core 6, Section 6 is most probably late Eocene, or possibly early Oligocene. The Eocene age is based on the absence of *Rounded apex triangle* (which is abundant in the sample immediately above). This taxon occurs in relatively high numbers with a coherent range in Oligocene and Neogene sequences (Kaneps et al., 1981, p. 328). Until more data are obtained, the correlation of the first appearance of *Rounded apex triangle* cannot be used confidently to mark the Eocene/Oligocene boundary, but that event is used in this study as the boundary marker.

The sample from Hole 576B, Core 5, Section 3 was taken to supplement a gap left in the coring of Hole 576. This sample and the first three sections of Core 7 are assigned an Eocene age on the basis of taxa commonly found in the Eocene Epoch (*Triangle broad wing, Tanged triangle, Triangle pointed margin ends*) and the absence of younger and older taxa.

The Paleocene/Eocene boundary occurs in Core 7, most probably between Sections 3 and 5. Sections 5 and 6 of Core 7 and Section 1 of Core 8 are of Paleocene age, on the basis of the presence of *Beveled triangle concave base* and *Triangle modified margin ends*.

Additional levels of correlation in "red" clay sequences are the two striking peaks in ichthyolith abundances within the Oligocene or latest Eocene and near the Paleocene/Eocene boundary (Doyle and Riedel, 1979b, 1980, 1981). The right-hand column of Table 2 gives the number of triangular ichthyoliths in a gram of dry sample. The Oligocene or latest Eocene peak occurs in Sample 576-6-3, 69–75 cm; the Paleocene/Eocene peak is in Sample 576-7-5, 68–74 cm.

Table 2. Occurrences of previously described taxa in samples from Deep Sea Drilling Project Leg 86.

Other microfossil zones[a]	Age: Ichthyoliths: Conventionally determined epoch boundaries	Age: Ichthyoliths: Probabilistically determined epoch boundaries	Sample (interval in cm)	Depth to top of sample (m)	*Centrally striated triangle*	*Spiky palmate*	*Triangle smooth surface*	*Triangle square inline*	*Triangle long inline*	*Triangular toothed*	*Striated blunt triangle*	*Wide triangle projection*	*Narrow triangle sharply pointed*	*Prominent polygon*	*Plain and lined lanceolate*	*Prominence with wye-line*	*Pointed and skirted*	*Wide crescent*	*Narrower crescent*	*Five peaks flared base*	*Triangle sigmoid rough*	*Triangle curved base*	*Triangle pointed margin ends*	*Triangle inline halfway*
			Hole 576, 576B																					
R: *Stylatractus universus* (Quaternary)			576-2-3, 118–125	11.38																				
			576-2-6, 108–114	15.70																				
			576-3-3, 58–65	13.18																				
	Miocene or younger		576-4-1, 8–14	19.88																				
		Mioc./Plio.	576-4-3, 58–65	22.68										1										
			576-4-6, 98–104	27.58																				
	Mioc. late	Oligo./Mioc.	576-5-6, 59–65	33.19																				1
	Oligocene		576-6-3, 69–75	35.79											?									2
	Eocene		576-6-6, 59–65	39.49											1								5	
			576B-5-3, 68–74	42.38											1				1					
		Eoc./Oligo.	576-7-1, 58–64	45.18									1										3	
		Paleoc./Eoc.	576-7-2, 88–94	46.98																			13	2
			576-7-3, 69–75	47.79																			5	1
			576-7-4, 68–74	49.28										1	1		1					1	7	
	Paleocene		576-7-5, 68–74	50.78											1							1	36	
			576-7-6, 15–25	52.28						1			2	1		1								
			576-8-1, 15–25	54.40		2	?							1		1								
			Hole 576A																					
R: *Stylatractus universus* (Quaternary)			576A-1-1, 140–150	3.60																				
R: Quaternary ?			576A-1-3, 140–150	6.60																				
D: Quaternary			576A-1-5, 140–150	9.60																				
Pliocene			576A-2-1, 140–150	12.30																				
Miocene			576A-2-3, 140–150	15.30																			1	
			576A-2-5, 140–150	18.30																				
	Miocene late		576A-3-1, 140–150	21.80																				
		Mioc./Plio.	576A-3-3, flow-in	24.80																				
			576A-3-5, 140–150	27.80																				
			576A-4-1, 140–150	31.30																				
		Oligo./Mioc.	576A-4-3, 140–150	34.30																				
	Oligo. late		576A-4-5, 140–150	37.30																1			9	
	Oligo. early	Eoc./Oligo.	576A-5-1, 140–150	40.80																			2	
	Eocene		576A-5-3, 140–150	43.80											1					1			7	1
		Paleoc./Eoc.	576A-5-5, 140–150	46.90																			10	
	Paleocene		576A-6-1, 140–150	50.30										2	3	1						1	18	
		Cret./Paleoc.	576A-6-3, flow-in	53.30			1					2		1	2	1								
N: *Tetralithus trifidus*	Cretaceous		576A-6-5, 140–150	56.30	3	30	29	18	22	1	12	17		18										
			576A-7-1, 140–150	59.80							cf	1		1										
N: *Broinsonia parca*–*Eiffellithus eximius*			576A-7-3, 140–150	62.80					2	1	10	1	1	2	1		1	1	2					
			576A-7-5, 140–150	65.80				1			2													

Note: Subtypes are arranged in order of their earliest occurrence in GPC-3. Numbers in the body of the table represent the total number of specimens found. Numbers in the third column from the right are the total number of triangular ichthyoliths in each sample. In Section 576A-2-1, several hundred ichthyoliths are present, but exact count cannot be made because the preparations are obscured by radiolarians. Question marks represent broken specimens in samples with no complete specimens of the subtype; "cf." indicates specimens that are similar, but do not fit the name description exactly. Age assignments based on microfossils other than ichthyoliths are from site summaries and S. Monechi's nannofossil stratigraphy chapter (this volume).

[a] R = radiolarian, D = diatom, N = nannofossil.

Hole 576A

Samples from this hole were taken as part of a geotechnical study of a "type" red clay section. The cores were cut into sections, but were left unsplit. A 10-cm, whole-round slice was cut from the end of each section and an approximately 100-cm^3 sample for biostratigraphic study was taken within that interval. Concentrations of ichthyoliths and dry weights of samples are given in the right-hand column of Table 2.

Ichthyoliths in Cores 1 and 2 are latest Miocene or younger based on the coherent range of *Narrow triangle ragged base*. Cores 3 and 4, Sections 1 and 3, are Miocene with a rich and diverse assemblage of characteristic Miocene taxa. Representative subtypes are *Two triangles, Triangle sinuous inline, Elliptical with line across*, and *Triangle irregular base*. Core 3, Section 3 contains an aberrant, very sparse assemblage of foraminifers, radiolarians, diatoms, and ichthyoliths. The ichthyoliths indicate only that this sample is Miocene.

Recognition of the Oligocene depends at present on the characteristic order of first appearances of several of the most dependable subtypes. In samples from the Pacific dated by other microfossils, the first appearance of *Rounded apex triangle* corresponds with nannofossil Zone CP16, the first appearance of *Triangle with high inline apex* with nannofossil Zone CP17, and the first appearance of *Small triangle long striations* with Zone CN1. This succession is also present in sequences without other microfossils (Edgerton et al., 1977; Doyle and Riedel, 1979b, Kaneps et al., 1981; Gottfried et al., 1985). In Hole 576A, this places (along with some supporting evidence from less common taxa—*Flexed triangle shallow inbase ≥120, Rectangular saw-toothed, Triangle with base angle*) the Oligocene/Miocene boundary between Sections 3 and 5 of Core 4, and the Eocene/Oligocene boundary between Sections 1 and 3 of Core 5. The lower part of Core 4 (Sample 576A-4-5, 140–150 cm) is probably late Oligocene, and the upper part of Core 5 (Sample 576A-5-1, 140–150 cm) probably early Oligocene.

Table 2. (Continued).

Triangle with triangular projection	Flexed triangle shallow inbase	Beveled triangle mid inline	Short triangle bowed inline	Giant lanceolate	Triangle concave base	Triangle medium wing	Wide triangle	Triangle short wing	Triangle broad wing	Triangle transverse line across	Narrow triangle cross-hachured	Tanged triangle	Small triangle crenate margin	Triangle one canal above	Broad triangle parallel inline	Wide triangle straight inbase	Triangle hooked margin	Narrow triangle straight inbase	Triangle double flex	Triangle sigmoid	Small dendritic few radiating lines	Triangle with parallel inline	Pointed triangle short inline	Triangle with canals	Pointed triangle long margins	Rounded apex triangle	Flexed triangle shallow inbase ≥ 120	Triangle with base angle	Triangle with high inline apex	Triangle inward angle	Small dendritic many radiating lines	Large with numerous lines	Rectangular saw-toothed	Two triangles	Short triangle stepped margin	Asymmetrical peak depression	Curved triangle pointed margin	Elliptical with line across	Small triangle long striations	Circular with line across
	1																												1						1			1	2	
2																													6						1			5	2	1
																													3									3	2	1
	1																												3						1			2		1
																		1								3		1	3					1	3			3	3	1
1	2					1		1							1		1				4			1	1	12		3	cf		3	2	1	1					8	
11	5			?		2		2		1	3		1		12		1			6						11	1									??	1			
12					cf	3		3		1	1				2		1	2																						
13	2					5				2	1				2	2	2		1																					
3	2				1	2		2		1		3			1		1			2																				
9	1				3	7		2				1			1		1	2								?			2											
6	2					3				7				1				10																						
7					2	7				4			1					2																						
10					5	6				3																														
1																																								
																										2												5	1	
	1															1										5		1	2				1		2			17	1	13
	1															1	1									2			6			1		1	3		?	13	3	5
	2															3		4								2			31					2	2		1	4	15	1
	1																2	1								1			10						1		2	5	12	11
1	1															2	2	5								4			15			1		2	1		1	10	19	1
	1																1									5			4				6		3		1	7	21	6
																																1		1				13	2	
1	6																				1				1	2			10				1		1		1	4	6	1
2	3						2			1						1	1	1			1				2	2			15		1	1	4	2	2		5	2	6	3
11	4					1	2	?						1	1		5	1	1		3				1	6	3	1	6		2	3	2	2	2	1	1		4	
11	3					9	1			2	1				13	1	4	1	2	1	1		13	1		4	4		2				2				1			
14	3				1	3		1		4				1	2				1	2			1	1		4	2			1		?								
21						5	2	1		3	1	1			1																									
11	1				5	2		1		1		6				1	1																							
37				2	10	22	1	9		7		3						1																						
						1																																		

Sections 3 and 5 of Core 5 are Eocene, based on the absence of younger taxa and the presence of subtypes characteristically found in abundance in the Eocene: *Triangle with triangular projection, Triangle pointed margin ends*, and *Triangle medium wing.*

The Paleocene/Eocene boundary is placed between Core 5, Section 5, and Core 6, Section 3, on the basis of the presence of *Beveled triangle concave margins* in the sample from Section 3. The first appearance in the sequence of several taxa (*Triangle radiating inline, Narrow straight triangle, Triangle pointed margin ends*) in Section 1 of Core 6 suggests this sample is also Paleocene.

The Cretaceous/Tertiary boundary is between Sections 3 and 5 of Core 6. The Cretaceous assemblages in Core 6, Section 5 and Core 7 include the subtypes *Striated blunt triangle, Triangle long inline, Triangle square inline*, and *Wide triangle projection.*

Concentrations of triangular ichthyoliths in the sequence (right-hand column of Table 2) show a peak of abundance in Sample 576A-6-1, 140–150 cm which is judged, on present evidence, as late Paleocene. While there is an increase in ichthyolith abundance in samples considered Oligocene (Samples 576A-4-5, 140–150 cm and 576A-5-1, 140–150 cm), the typical middle Tertiary concentration of 40–45 triangular ichthyoliths per gram is not detected by our sampling.

Hole 576B

Six channel samples were taken from Core 6, Sections 2 and 3 to determine the location of the Cretaceous/Tertiary boundary. A narrow groove of sediment was scraped from the middle surface of the split core yielding a sample of approximately 40 cm^3.

Both Sections 2 and 3 of Core 6 are Paleocene, placing the Cretaceous/Tertiary boundary between 54.10 m (the top of Section 4 in Core 6) and 55.40 m, the level at which Maestrichtian nannofossils occur (see Site 576 chapter, this volume). A comparison of the distribution of the newly described taxa in Hole 576B with Site 577 and the other sequences shown in Table 4 suggests that Section 3 correlates with nannofossil zones older than Zone CP5.

Concentrations of triangular ichthyoliths show a peak abundance in Sample 576B-6-2, 50–100 cm which corre-

Table 2. (Continued).

Age: Other microfossil zones[a]	Age: Ichthyoliths: Conventionally determined epoch boundaries	Age: Ichthyoliths: Probabilistically determined epoch boundaries	Sample (interval in cm)	Depth to top of sample (m)	*Short rectangular with striations*	*Long rectangular with striations*	*Triangle sinuous inline*	*Stippled triangle*	*Long triangle short inline*	*Long ellipse*	*Triangle concave first margin*	*Long triangle stepped margin*	*Narrow triangle ragged base*	*Triangle irregular base*	*Triangle double inline*	Total number of triangular (*a8,9*) ichthyoliths in sample	Total dry weight of sample (g)	Number of triangular (*a8,9*) ichthyoliths in 1 g
			Hole 576, 576B															
			576-2-3, 118-125	11.38							1					65	21.79	2.98
R: *Stylatractus universus* (Quaternary)			576-2-6, 108-114	15.70						1		1		1	1	107	18.88	5.67
			576-3-3, 58-65	13.18			1				1	1		1		56	17.86	3.14
	Miocene or younger		576-4-1, 8-14	19.88	1		1						1			89	19.10	4.66
		Mioc./Plio.	576-4-3, 58-65	22.68	2		1			2		1		1		84	21.98	3.82
			576-4-6, 98-104	27.58												Barren	29.37	Barren
	Mioc. late Oligocene	Oligo./Mioc.	576-5-6, 59-65	33.19					6	1	1				1	270	25.20	10.17
			576-6-3, 69-75	35.79												907	28.59	31.72
			576-6-6, 59-65	39.49												796	25.47	31.25
			576B-5-3, 68-74	42.38												459	24.60	18.66
	Eocene	Eoc./Oligo.	576-7-1, 58-64	45.18												339	32.81	10.33
		Paleoc./Eoc.	576-7-2, 88-94	46.98												683	30.89	22.11
			576-7-3, 69-75	47.79												512	26.64	19.22
			576-7-4, 68-74	49.28												585	25.46	22.98
			576-7-5, 68-74	50.78												2002	28.98	69.08
	Paleocene		576-7-6, 15-25	52.28												740	33.96	21.18
			576-8-1, 15-25	54.40												38	25.09	1.51
			Hole 576A															
R: *Stylatractus universus*			576A-1-1, 140-150	3.60						3		2		3	1	93	54.81	1.70
(Quaternary)			576A-1-3, 140-150	6.60	2					2	6	1	1	5		150	76.21	1.97
R: Quaternary ?			576A-1-5, 140-150	9.60	2			1		1	4		1	2		179	81.45	2.20
D: Quaternary			576A-2-1, 140-150	12.30	2					3	7			4		—	45.26	—
Pliocene			576A-2-3, 140-150	15.30	3	3	1			1		1	1	5		225	65.83	3.87
Miocene			576A-2-5, 140-150	18.30	2	1	4			2	1	1	2	7		368	73.91	4.98
			576A-3-1, 140-150	21.80	1		3			2	7	1	1	6	1	389	74.11	5.25
		Mioc./Plio.	576A-3-3, flow-in	24.80			1			5	1			1		9	69.10	0.13
	Miocene late		576A-3-5, 140-150	27.80		1			2	1	2	1		9		437	52.72	8.29
			576A-4-1, 140-150	31.30			1				1		cf			462	48.11	9.60
		Oligo./Mioc.	576A-4-3, 140-150	34.30			1		2							539	38.61	13.96
	Oligo. late		576A-4-5, 140-150	37.30												2226	94.81	23.48
	Oligo. early	Eoc./Oligo.	576A-5-1, 140-150	40.80												951	50.79	18.72
	Eocene		576A-5-3, 140-150	43.80												586	79.70	7.35
			576A-5-5, 140-150	46.90												234	66.95	3.50
		Paleoc./Eoc.	576A-6-1, 140-150	50.30												5526	89.44	61.78
	Paleocene		576A-6-3, flow-in	53.30												1130	87.28	12.95
N: *Tetralithus trifidus*		Cret./Paleoc.	576A-6-5, 140-150	56.30												1250	87.99	14.27
			576A-7-1, 140-150	59.80												61	—	—
N: *Broinsonia parca–Eiffellithus eximius*	Cretaceous		576A-7-3, 140-150	62.80												341	101.25	3.37
			576A-7-5, 140-150	65.80												36	154.90	0.23

sponds with abundances found at the late Paleocene, or earliest Eocene, level in other pelagic clay sequences (Table 3; Doyle and Riedel, 1979b; Kaneps et al., 1981).

Site 578

Thirteen standard samples 40 cm^3 in size and two samples (Sections 578-17-4 and 578-19-2) of approximately 80 cm^3 were examined from this hole.

Ichthyoliths in samples from Cores 11–14 are not numerous but are in agreement with the Pliocene and late Miocene ages of the siliceous microfossils. The co-occurrence of *Long ellipse* and *Long triangle short inline* in Core 14, Section 2 indicates that sample is late Miocene (discussed in second paragraph under Hole 576). The presence of *Circular with line across* and *Short rectangular with striations* in Core 16, Section 2 indicates a middle Miocene age.

The Oligocene/Miocene boundary falls between Core 17, Section 4 and Section 5, and the Eocene/Oligocene boundary between Core 17, Section 5, and Core 18, Section 1. The Oligocene is identified by the presence of *Rounded apex triangle* and *Triangle with base angle* and the absence of *Small triangle long striations*. It is not possible for us to tell from the available data whether some part of the Oligocene and early–middle Miocene is missing or if sediment accumulation was very slow.

Cores 18 and 19, Section 1 are Eocene. The absence of *Triangle curved base* (which ranges in samples dated by calcareous nannofossils from Zone CP11 to Zone CP2) from the upper part of this interval, and its presence in the lower, suggests that Sections 1 and 3 of Core 18 are late to middle Eocene and Section 4 of Core 18 and Section 1 of Core 19 are middle to early Eocene.

The Paleocene/Eocene boundary is in Core 19, between Sections 1 and 3. The presence of *Beveled triangle concave margins* in Section 578-19-2, as well as the first appearance of *Triangle radiating inline* and *Narrow straight triangle*, suggests that Section 2 is Paleocene, but the extension of typically Paleocene forms into earliest Eocene has not been studied sufficiently to allow a confident Paleocene age assignment to this sample. Section 3 is Paleocene. *Short triangle bowed inline* and *Bev-*

eled triangle concave margins are present in the sample from this section, both forms restricted to Paleocene assemblages.

Concentrations of triangular ichthyoliths peak in Sample 578-17-5, 69–75 cm, corresponding with an Oligocene age assigned on the basis of ichthyolith biostratigraphic evidence. The characteristic high spike in abundance at the Paleocene/Eocene boundary is not evident in this hole, perhaps due to sample spacing.

Site 581

One standard sample of 40 cm^3 was taken from Core 10 to corroborate the Miocene age of diatoms found within the cherts of Core 12.

Ichthyoliths are sparse, but the presence of *Small triangle long striations* as well as *Rectangular saw-toothed, Triangle with high inline apex*, and *Triangle medium wing* indicates that the sample is Miocene, most probably early or middle (Table 3).

PROBABILISTIC STRATIGRAPHY

Although the conventional procedures employed above for stratigraphic interpretation have served us reasonably well in the past, when the number of known ichthyolith sequences was small and manageable, we are approaching the stage at which the body of data will be so large as to require its automated (computerized) accessing and manipulation. This is true to some extent for all microfossil groups, but the problem is particularly acute for the ichthyoliths. Their commonly sparse and intermittent occurrences in sedimentary sequences make it difficult to make syntheses that take account of the different levels of reliability to be placed on each particular upper or lower stratigraphic limit of a subtype in each sequence in which it is observed.

The procedures of probabilistic stratigraphy, developed first by Hay (1972) and applied, for example, by Blank and Ellis (1982), offer a promising route toward the integration of data from large numbers of sequences, but they have the shortcoming that they depend on the principle of "majority rule." For example, in determining the most-likely-correct stratigraphic succession, three occurrences of a pair of events in one order of succession outweighs two occurrences of those same events in the opposite order, although the evidence for the former three may be very weak and the evidence for the latter two very strong. It is to take account of the inequalities in the strength of the different items of evidence that Riedel (1981), Westberg and Riedel (1982), and Riedel and Westberg (1982) developed a means of indexing the reliability of single biostratigraphic events in single sequences.

This procedure has been applied to ichthyolith data by Gottfried et al. (1984), and a further step is made here by applying the probabilistic procedure of Hay to a substantial body of stratigraphic data from the North Pacific, weighted according to their indices of reliability. We have taken account of three of the four factors used by Gottfried et al. in assessing reliabilities, with only one minor change to the factor scores, as shown in Table 5. The omitted factor concerns the limits of geographic distribution of certain subtypes of ichthyoliths, which we now feel not to be sufficiently well known to provide a reliable multiplier. In better understood fossil groups, the number of factors used in assessing these reliabilities is as high as a dozen or more, and the number applied to ichthyoliths will increase as we gain experience in using the procedure.

As the basis for a probabilistic ichthyolith stratigraphy for the western North Pacific, we have used data from seven sequences—Holes 576, 576A, and 578 from Leg 86, three from the MPGII localities listed in the Introduction, and piston core GPC-3 (Doyle and Riedel, 1979b). In each of these sequences we looked for all of the subtypes that have so far been described (with the exception of *Triangle complex transverse line, Flexed triangle 102–112, Flexed triangle 115–118,* and *Flexed triangle 120–128*, the concepts of which are under revision) and recorded the abundances of all that we encountered (79 subtypes). The upper and lower limits of the ranges of the most dependable of the taxa (58 subtypes) were weighted according to the products of the scores of the three factors used (the right-hand numbers in each of the seven main columns of Table 6) and then arranged in the most probable stratigraphic order (the order in which they appear in Table 6) by the procedure of Hay, modified so that the contribution of each pair of events to the matrix depends on their reliability indices.

The mean of the reliabilities of each event at the seven sites is shown toward the right side of Table 6. The second-last column of that table shows the nannofossil zone in which each event is thought to occur, using the conventional stratigraphic procedures discussed in the previous section. Epoch boundaries are placed against the calcareous nannofossil zones in accordance with the scheme of Okada and Bukry (1980). The extent of uncertainty in placement of boundaries between the Tertiary epochs, against the probabilistically ordered list of ichthyolith events, was derived from the calcareous nannofossil ages of those ichthyolith events that have high mean reliability indices (>0.25). The wide intervals of uncertainty in placing epoch boundaries depends partly on our requiring these high mean reliability indices and partly on the fact that the probabilistically derived succession of ichthyolith events violates to some extent the order of ages indicated by the ties to the calcareous nannofossil zonation. The latter problem will undoubtedly be reduced as more sequences are incorporated into the data base (thereby allowing successions of events with high reliability indices to correct errors), but there will probably remain a residue of inconsistencies due to some calcareous nannofossil age determinations being less soundly based than others and, to that extent, unreliable. If sufficient data were available on the nannofossil occurrences to permit determination of reliability indices, these could be handled probabilistically along with the ichthyolith data to provide a uniform, integrated succession.

The indicated epoch boundaries, with their ranges of uncertainty, were then carried into the body of the table, to determine their levels in each of the Leg 86 sequences (with the results shown in the third column from the left

Table 3. Occurrences of previously described taxa in samples from Deep Sea Drilling Project Leg 86.

Other microfossil zones[a]	Age: Ichthyoliths: Conventionally determined epoch boundaries	Age: Ichthyoliths: Probabilistically determined epoch boundaries	Sample (interval in cm)	Depth to top of sample (m)	*Centrally striated triangle*	*Spiky palmate*	*Triangle smooth surface*	*Triangle square inline*	*Triangle long inline*	*Triangular toothed*	*Striated blunt triangle*	*Wide triangle projection*	*Narrow triangle sharply pointed*	*Prominent polygon*	*Plain and lined lanceolate*	*Prominence with wye-line*	*Pointed and skirted*	*Wide crescent*	*Narrower crescent*	*Five peaks flared base*	*Triangle sigmoid rough*	*Triangle curved base*
			Hole 576B																			
	Paleocene		576B-6-2, 0-50	51.10											1				1			5
			576B-6-2, 50-100	51.60										2	1		2					2
			576B-6-2, 100-150	52.10												1					1	
			576B-6-3, 0-50	52.60																		1
			576B-6-3, 50-100	53.10															1		2	
			576B-6-3, 100-150	53.60						?						2			1			
			Hole 577																			
N: *Discoaster barbadiensis* CP15	Eocene late		577-7-5, 100-107	61.30																		
N: *Reticulofenestra umbilica* CP14	mid to		577-8-3, 23-31	67.03											1					3		
N: *Discoaster binodosus* CP9b	early		577-9-5, 32-40	79.92																		
N: CP7/CP8	Paleo-cene late		577-10-3, 31-39	87.11																		
N: CP5/CP6			577-10-5, 122-130	90.02						1					1	1						2
			577-11-2, 31-39	94.11										1								
N: *Fasciculithus tympaniformis* CP4	early		577-11-4, 122-130	98.02										1								
N: *Chiasmolithus danicus* CP2			577-11-6, 120-128	101.00																		1
N: *Zygodiscus sigmoides* CP1			577-12-3, 82-90	105.62											1	2						
N: *Micula mura*	Cretaceous		577-12-6, 82-90	109.12		3	2				1			1								
			Hole 578																			
R: *Sphaeropyle langii*			578-11-2, 96-102	92.46																		
R: *Stichocorys peregrina*			578-12-2, 108-114	102.38																		
D: *Thalassiosira convexa*			578-13-2, 107-114	111.87																		
	Miocene late		578-14-2, 108-114	121.38																		
	middle to early		578-15-2, 79-85	130.29																		
		Mio./Plio.	578-16-2, 77-83	140.07																		
			578-17-3, 92-98	151.22														1				
		Oligo./Mio.	578-17-4, 140-150	153.20														1				
	Oligocene		578-17-5, 69-75	154.09																		
	Eocene late to middle		578-18-1, 78-84	157.58																		
			578-18-3, 74-80	160.54																		
F: early middle Eocene P9-11	middle to early	Eoc./Oligo.	578-18-4, 79-85	162.09											1					1		1
		Paleoc./Eoc.	578-19-1, 76-82	166.96																		1
			578-19-2, 140-150	169.20									2	1		1						1
	Paleocene		578-19-3, 79-85	170.09									4	1								1
			Hole 581																			
	Miocene		581-10-4, 70-76	262.70																		

Note: Conventions as in Table 2.
[a] N = nannofossil, R = radiolarian, D = diatom, F = foraminifer.

in Tables 2 and 3). This step at present involves a considerable amount of subjective judgement, but we expect in the future to be able to establish rules that will permit it to be done with a degree of objectivity and reproducibility. At present, the placement of each epoch boundary in each sequence depends simply on an *ad hoc* evaluation of the evidence on the levels of occurrence, and the indices of reliability, of the probabilistically ordered events in the core concerned. Because of the sparse occurrence of individual subtypes of ichthyoliths and departures of individual sequences from the most probably correct order of events, the intervals of uncertainty in placement of epoch boundaries in individual cores tend to be larger than those in the placement of those boundaries against the probabilistically ordered list of events.

SYSTEMATIC SECTION

Seven new subtypes that first appear in the Paleocene are described below. The procedure for describing and naming the ichthyoliths involves use of a string of letters and numbers corresponding to objectively defined characters of the image as seen in a transmitted-light microscope. These name descriptions can be decoded in full by reference to Doyle and Riedel (1979a, 1980) and Gottfried et al. (1984). Distinctive features necessary to distinguish each subtype from described and undescribed forms are pointed out in the text. The coded descriptions are frequently long, and therefore colloquial names are coined to act as their surrogates.

In order to differentiate the newly described subtypes, the following changes to the descriptive system are required.

1. Under Type *a8/b1,5,* add the character

   g. Shape of prominent flexure

      1. angle/angle

      2. angle/curve

Table 3. (Continued).

Triangle pointed margin ends	*Triangle inline halfway*	*Triangle with triangular projection*	*Flexed triangle shallow inbase*	*Beveled triangle mid inline*	*Short triangle bowed inline*	*Giant lanceolate*	*Triangle concave base*	*Triangle medium wing*	*Wide triangle*	*Triangle short wing*	*Triangle broad wing*	*Triangle transverse line across*	*Narrow triangle cross-hachured*	*Tanged triangle*	*Small triangle crenate margin*	*Triangle one canal above*	*Broad triangle parallel inline*	*Wide triangle straight inbase*	*Triangle hooked margin*	*Narrow triangle straight inbase*	*Triangle double flex*	*Triangle sigmoid*	*Small dendritic few radiating lines*	*Triangle with parallel inline*	*Pointed triangle short inline*	*Triangle with canals*	*Pointed triangle long margins*	*Rounded apex triangle*	*Flexed triangle shallow inbase ≥ 120*	*Triangle with base angle*	*Triangle with high inline apex*	*Triangle inward angle*	*Small dendritic many radiating lines*	*Large with numerous lines*	*Rectangular saw-toothed*	*Two triangles*	*Short triangle stepped margin*	*Asymmetrical peak depression*	*Curved triangle pointed margin*	*Elliptical with line across*	*Small triangle long striations*	*Circular with line across*	*Short rectangular with striations*	*Long rectangular with striations*	*Triangle sinuous inline*	*Stippled triangle*	*Long triangle short inline*	*Long ellipse*
3		9	1				2	3		1		4						1																					2									
4		5					5	3		3		3																																				
2		2			1		1																																									
					1		2	cf													cf																											
				3																																												
		30	1					2		1		1	3	3			1			1							2						1															
1		25	5					?				2	2				1										1																					
1		6						1																																								
7		5						2																																								
		3						1																																								
2		6					1					1			1																																	
1		4			1		1	1			cf																																					
cf		1		cf			1	1				1																																				
				1																																												
																																								1								
																																								1				1				
																	1		1											1										2								
																		1												4						1			1	6		1		1		2	1
																		1									1			1				5						3					1		
																1		4		1						2		1				2	1						2	1	1					
		2	9					1	1	2								1	2		2						7			1				1						4							
		3	7					3		6		1					2			1		2	2	4			1	35		4	1			1							2							
		6	5			1		2	1			6						2	2			1	1	1				14		2																		
2		8	1					3		1	1		1				1																															
5		17						2				?						2																														
6		10					2	2	1					1			1	6				2																										
18		11	1				1			4			2	4				2		1																												
62		10					6	10		1																																						
4		4			3		4	7																																								
																				1											1				1						3							

2. Under Type *a8/b1,5,* add the character

h. Shape of transverse line

0. indeterminable

1. straight line terminating at margins at approximately the same level

2. simply curved or straight line terminating at margins at different levels ("perpendicular" distances from apex of outline to the levels at which the transverse line intersects the margins differ by at least 5%)

3. straight or simply curved line extending across sides of inline; one end running through area between inline and outline, the other terminating at the flexed margin

DESCRIPTIONS OF NEW TAXA

a8/b1,5/c1/d1/e0/f23–38/g2/h2 new subtype
Flexed triangle asymmetric
(Plate 1, Figs. 1–5)

Characters: A distinctive triangular form with one margin modified by a prominent flexure. The flexure nearer the apex is sharply angled, that nearer the base smoothly curved. Transverse line, or base when transverse line absent, a simply curved or straight line terminating at margins at different levels. Overall length 360–1100 μm, maximum width 120–300 μm.

Distinction from similar forms: The prominent curved flexure modifying one margin readily distinguishes this taxon from most co-occurring forms. A similar form found in the Cretaceous differs in that the transverse line does not terminate at both margins. In the Cretaceous form the transverse line extends across the sides of the inline, one end

Table 3. (Continued).

Other microfossil zones[a]	Age: Ichthyoliths: Conventionally determined epoch boundaries	Age: Ichthyoliths: Probabilistically determined epoch boundaries	Sample (interval in cm)	Depth to top of sample (m)	*Triangle concave first margin*	*Long triangle stepped margin*	*Narrow triangle ragged base*	*Triangle irregular base*	*Triangle double inline*	Total number of triangular (*a8,9*) ichthyoliths in sample	Total dry weight of sample (g)	Number of triangular (*a8,9*) ichthyoliths in 1 g
			Hole 576B									
	Paleocene		576B-6-2, 0-50	51.10						964	26.81	35.95
			576B-6-2, 50-100	51.60						1387	23.90	58.03
			576B-6-2, 100-150	52.10						962	23.09	41.66
			576B-6-3, 0-50	52.60						547	20.19	26.79
			576B-6-3, 50-100	53.10						289	23.14	12.49
			576B-6-3, 100-150	53.60						90	25.06	3.67
			Hole 577									
N: *Discoaster barbadiensis* CP15	Eocene late		577-7-5, 100-107	61.30						836	62.33	13.41
N: *Reticulofenestra umbilica* CP14	Eocene mid to		577-8-3, 23-31	67.03						695	72.99	9.52
N: *Discoaster binodosus* CP9b	Eocene early		577-9-5, 32-40	79.92						283	90.67	3.12
N: CP7/CP8	Paleocene late		577-10-3, 31-39	87.11						572	66.77	8.57
N: CP5/CP6			577-10-5, 122-130	90.02						126	64.14	1.96
			577-11-2, 31-39	94.11						254	50.19	5.06
N: *Fasciculithus tympaniformis* CP4			577-11-4, 122-130	98.02						260	67.74	3.84
N: *Chiasmolithus danicus* CP2	Paleocene early		577-11-6, 120-128	101.00						252	76.96	3.27
N: *Zygodiscus sigmoides* CP1			577-12-3, 82-90	105.62						112	53.15	2.11
N: *Micula mura*	Cretaceous		577-12-6, 82-90	109.12						48	58.77	0.82
			Hole 578									
R: *Sphaeropyle langii*			578-11-2, 96-102	92.46	1					21	24.32	0.86
R: *Stichocorys peregrina*			578-12-2, 108-114	102.38	1					14	24.52	0.57
D: *Thalassiosira convexa*			578-13-2, 107-114	111.87						11	28.71	0.38
	Miocene late		578-14-2, 108-114	121.38		1				82	23.91	3.43
	Miocene middle to early		578-15-2, 79-85	130.29		1				144	33.43	4.31
		Mio./Plio.	578-16-2, 77-83	140.07						123	40.91	3.01
			578-17-3, 92-98	151.22						309	35.47	8.71
		Oligo./Mio.	578-17-4, 140-150	153.20						1274	105.16	12.12
	Oligocene		578-17-5, 69-75	154.09						1357	31.02	43.75
	Eocene late to middle		578-18-1, 78-84	157.58						356	38.11	9.34
			578-18-3, 74-80	160.54						301	30.03	8.35
F: early middle Eocene P9-11	Eocene middle to early	Eoc./Oligo.	578-18-4, 79-85	162.09						692	46.47	14.89
		Paleoc./Eoc.	578-19-1, 76-82	166.96						966	37.44	25.80
			578-19-2, 140-150	169.20						2221	139.63	15.90
	Paleocene		578-19-3, 79-85	170.09						860	41.74	7.90
			Hole 581									
	Miocene		581-10-4, 70-76	262.70						161	27.45	5.86

running through the area between inline and outline, the other terminating at the flexed margin. In similar forms in later Cenozoic assemblages (see Doyle et al., 1974, pl. 2H, figs. 5–13), the flexure nearest the base is sharply angled or with a slight curve (see Doyle et al., 1974, pl. 2H, fig. 9) and the transverse line intersects only the flexed margin.

Occurrence: In middle and upper Paleocene and earliest Eocene, in sequences with age assigned on the basis of ichthyoliths (see Table 4). Not present in reference samples from Site 577.

a9/b1,5/c1,13/d1,13/e1/f1/g1/h0,5/i6/j2,3/k3,14/m0.35–0.75/n1.3–2.0/p0/q0,2,6,7/r0,1/s1/t1/z4/cc0/dd0/ee0/ff0/gg0/hh0/jj2/kk2/mm0/nn0 new subtype
Triangle modified margin ends
(Plate 2, Figs. 6–9)

Characters: Curved triangular form (length-to-width ratio 1.3–2.0) with one margin and occasionally both margins modified by a shallow inward angle or base of margins inwardly curved in bottom one-fourth. Apex between sharp and blunt. Sides of inline bowed in, or acuminate with sides below apical portion straight and divergent. Apex of inline in lower two-thirds of tooth. Base, or transverse line when present, an upwardly convex line slightly above the level of margin ends. Overall length 360–600 μm, maximum width 240–340 μm.

Distinction from similar forms: Some superficially similar forms (Doyle and Riedel, 1979b, pl. 7, figs. 16, 32, 35, 36) differ in either greater extension of the margin ends below the base of the inline, a more sharply pointed apex, or in having straight rather than curved margins. Other similar forms (Doyle and Riedel, 1979b, pl. 6, figs. 6, 16) possess canals or striations radiating out from the inline.

Occurrence: In early Paleocene (nannofossil Zone CP2) at Site 577. Occurs in lower part of Paleocene in sequences with ages assigned on the basis of ichthyoliths (Table 4).

a9/b1,5/c1/d1/e1/f4/g1/h0,5/i2,6/j2,3/k8/m0.14–0.25/n2.5–3.0/p0/q0,2/r0,1/s1/t1/z2/cc0/dd0/ee0/ff0/gg0/hh0/jj2/kk2/mm0/nn0 new subtype
Narrow straight triangle
(Plate 2, Figs. 1–5)

Characters: Narrow triangular form (length-to-width ratio 2.5–3.0) with lateral shadows, moderately rounded apex, straight base, and generally straight margins. Occasional specimens with one margin concave, the other convex. Inline approximately same shape as outline, extending into upper third of the outline. Transverse line, though seldom preserved, straight. Overall length 330–800 μm, maximum width 130–260 μm.

Distinction from similar forms: *Narrow straight triangle* is easily distinguished by the large length-to-width ratio, moderately rounded apex, and straight sides.

Occurrence: One broken specimen in late Paleocene (nannofossil Zone CP6) at Site 577. In sequences with ages based on ichthyoliths (see Table 4), ranges from late Paleocene through earliest Eocene.

Table 4. Distribution of newly described Paleogene taxa in Deep Sea Drilling Project Leg 86 sediments and in Giant Piston Core-3 (GPC-3).

Nannofossil zone	Age: Ichthyoliths	Samples (interval in cm)	*Triangle modified margin ends*	*Beveled triangle concave margins*	*Triangle curved pointed margins*	*Narrow triangle unequal margins*	*Triangle radiating inline*	*Narrow straight triangle*	*Flexed triangle asymmetric*
		Hole 576							
	Eocene	576-7-1, 58–64						?	
	Eocene	576-7-2, 88–94			2			1	
	Eocene	576-7-3, 69–75			1		2		
		576-7-4, 68–74			3		5		
	Paleocene	576-7-5, 68–74		1	7		8	?	
	Paleocene	576-7-6, 68–74	1	27					
	Paleocene	576-8-1, 15–25							
		Hole 576A							
	Paleocene	576A-6-1, 140–150			3		11	2	
	Paleocene	576A-6-3, 140–150		9	1				
		Hole 576B							
	Paleocene	576B-6-2, 0–50			6		14	3	
	Paleocene	576B-6-2, 50–100					10	5	
	Paleocene	576B-6-2, 100–150				2	7	1	5
	Paleocene	576B-6-3, 0–50	1	2		4	3		3
	Paleocene	576B-6-3, 50–100	3	2			3		
	Paleocene	576B-6-3, 100–150	2				1		
		Hole 577							
CP7/8	Paleocene, late	577-10-3, 31–39			8		4		
CP5/6	Paleocene, late	577-10-5, 122–130			1		1		
	Paleocene, late	577-11-2, 31–39			1		1	?	
CP4	Paleocene, late	577-11-4, 122–130		1	5		3		
CP2	Paleocene, early	577-11-6, 120–128			1				
CP1	Paleocene, early	577-12-3, 82–90	3						
		Hole 578							
	Paleocene	578-19-2, 140–150	?	3	1		9	4	
	Paleocene	578-19-3, 79–85					4		
		Giant Piston Core-3 — Depth (cm)							
	Eocene	1691–1708			2		2	3	1
	Paleocene	1750		2	1	1	4	5	1
	Paleocene	1789–1811		11	10	4	14	11	9
	Paleocene	1850		5	4	1	5	9	1
	Paleocene	1893–1912		23		2	6	6	1
	Paleocene	1950	2	15	2				
	Paleocene	1995–2008	8						
	Paleocene	2040							
	Cretaceous	2060							

Note: The new subtypes were searched for in all the Leg 86 samples, but only those samples in which they occur are listed. In GPC-3, samples above the 15-m level were not examined. Subtypes are arranged in order of their earliest occurrence in GPC-3.

Table 5. Factors and weights used to score the reliabilities of ichthyolith biostratigraphic events.

Factors	Multiplier 0.10	0.25	0.50	0.75	1.00
Abundance (number of specimens in each sample)		1	2–5		>5
Ease of distinguishing from co-occurring subtypes	Difficult		Moderately easy		Very easy
Constancy of occurrence, above or below the event			Interrupted		Constant

a9/b1,5/c1/d1/e1/f4 + (1,16)/g1/h0,5/i4/j4/k3,8/m0.5–0.75/ n1.6–1.8/p2.2–2.8/q0,3,6/r0,4/s1,2/t1/z4/cc0/dd0/ee0/ff0/gg0/ hh0/jj2/kk2/mm0/nn0 new subtype
Triangle curved margin ends
(Plate 3, Figs. 5–12)

Characters: Triangular form (length-to-width ratio between 1.6 and 1.8) with both margins curved basally and extending below base of inline. Inline approximately same shape as outline, or with sides bowed in, not extending into upper half of outline. Base of inline a straight or smoothly curved line. transverse line, when present, a simply curved line terminating at margins at same level. Lateral shadows present. Overall length, 110–325 μm, maximum width 65–200 μm.

Distinction from similar forms: In *Triangle pointed margin ends,* which co-occurs with *Triangle curved margin ends,* the base of each margin is modified by a shallow simple angle and is pointed (Doyle et al., 1974, pl. 2K, figs. 1,2). In *Triangle transverse line across,* apex of inline extends into upper half of tooth.

Occurrence: In the Paleocene (nannofossil Zone CP6–7) at Site 577. Ranges from late Paleocene through earliest Eocene in sequences correlated by ichthyoliths (see Table 4).

a9/b1,5/c1,13/d1/e1/f21/g1/h0,4,5/i2/j2/k7,8/m0.40–0.75/ n1.0–2.0/pl.0–2.4/q0,2,3,6/r0,1,2/s1,2/t1/z1,4/cc0/dd0/ee0/ff0/ gg0/hh0/jj2/kk2/mm0/nn0 + a8/b1,5/c1/d2/e100–140/f20–30/ g1,2/h0 new subtype
Triangle radiating inline
(Plate 1, Figs. 12–17)

Characters: Generalized group of triangular forms (range of length-to-width ratio 1.0–2.4) with approximately straight margins, one margin frequently modified by a shallow simple angle (not reflexed), or occasionally by a prominent flexure, in bottom quarter. Inline approximately same shape as outline, or parallel sided. Characteristic canals radiate out from inline. Overall length 130–400 μm, maximum width 60–200 μm.

Distinction from similar forms: Distinguished from forms of the same general description (Doyle and Riedel, 1979b, pl. 6, fig. 1, pl. 7, fig. 36) by the canals extending out from both the apex and sides of the inline.

Occurrence: In Paleocene (nannofossil Zones CP6–7) at Site 577. Distribution in sequences without other microfossils indicates a range through late Paleocene and into earliest Eocene (Table 4).

a9/b1,5/c13/d1,13/e1/f1/g1/h0,3,4/i2,3/j6/k8/m0.1–0.4/ n1.8–2.5/p2.2–2.6/q0,6/r0,1,2,3/s1,2/t1/z9/cc0/dd0/ee0/ff0/gg0/ hh0/jj0/kk0/mm0/nn0 new subtype
Narrow triangle unequal margins
(Plate 3, Figs. 1–4)

Characters: Triangular form without lateral shadows, one margin straight or convex and modified by a shallow angle in bottom one-fourth; the other margin concave, moderately to markedly longer, and occasionally modified by a shallow angle at the base. Length-to-width ratio 1.8–2.5. Inline approximately same shape as outline, extending into upper half of outline. Base of inline, or transverse line if present, a curved line, concave downward, terminating at margins at different levels. Overall length, 400–600 μm, maximum width 180–240 μm.

Distinction from similar forms: *Triangle concave base* (Doyle and Riedel, 1979b, pl. 6, fig. 7) has a rather similar name description, but lacks the angle at the base of the shorter margin. The two forms illustrated in figs. 18 and 19 of the plate cited above are narrower (length to width ratio >2.5).

Occurrence: Restricted to the Paleocene in sequences correlated by ichthyoliths (see Table 4). Not present in reference samples from Site 577.

a9/b1,5/c13/d13/e1/f1/g1/h0,5/i6,7/j6,7/k3,8,14/m0.25–0.60/ n1.3–2.0/p0/q0,2,6/r0,1,3/s1,2/t1/z4/cc0/dd0/ee0/ff0/gg0/hh0/ jj2/kk2/mm2/nn0 new subtype
Beveled triangle concave margins
(Plate 1, Figs. 6–11)

Characters: Triangle (length-to-width ratio 1.3–2.0) with both margins concave, usually with most of the curvature toward the base. Both margins modified by a simple angle (not reflexed) in bottom one-fourth. Apex moderately or sharply pointed. Inline in middle one-third of outline and approximately same shape as outline, or with sides bowed in, or acuminate apically and flared basally. Transverse line, or base when

Table 6. Most probable sequence of ichthyolith events derived from their occurrence in seven "unfossiliferous" pelagic clay sequences from the North Pacific.

Event		GPC-3		62PC		65PC		73PC		DSDP 576		DSDP 576A		DSDP 578		Rel. mean	Age	
		Up Lo	Rel	Up Lo	Rel	Up Lo	Rel	Up Lo	Rel	Up Lo	Rel	Up Lo	Rel	Up Lo	Rel		Nanno. zone	Epoch
► *Small triangle long striations*	T	0–49	0.25	0–60	1.00	0–60	1.00	0–120	1.00	0–1148	0.50	0–370	0.25	0–9246	0.25	0.61	CN15	
► *Elliptical with line across*	T	0–49	0.50	0–60	1.00	0–60	1.00	0–120	1.00	0–1148	0.25	0–370	0.50	11197–12148	0.13	0.63	CN15	
Triangle irregular base	T	49–110	0.13	0–60	0.25	0–60	0.50	0–120	0.13	1148–1580	0.06	0–370	0.25	0–0	0.00	0.19	CN15	
Triangle concave first margin	T	0–49	0.03	0–60	0.10	0–60	0.05	0–120	0.03	0–1148	0.01	370–660	0.05	9256–10248	0.01	0.04	CN15	
► *Long ellipse*	T	49–110	0.50	0–60	0.50	0–60	1.00	0–120	1.00	1148–1580	0.13	0–370	0.50	11197–12148	0.13	0.54	CN15	
Triangle with high inline apex	T	49–110	0.13	0–60	0.13	0–60	0.13	0–120	0.13	0–1148	0.13	370–670	0.06	10248–11197	0.13	0.12	CN15	
► *Rounded apex triangle*	T	49–110	0.13	0–60	0.50	0–60	0.25	0–120	0.50	1993–2278	0.25	0–370	0.25	12148–13039	0.25	0.30	CN15	
► *Circular with line across*	T	49–110	0.25	0–60	0.25	0–0	0.00	0–120	0.50	1148–1580	0.13	370–670	0.50	13039–14017	0.06	0.28	CN15	
► *Short rectangular with striations*	T	0–49	0.13	0–0	0.00	0–60	0.50	120–220	0.25	1328–1993	0.13	370–670	0.50	11197–12238	0.13	0.27	CN15	
Narrow triangle ragged base	T	49–110	0.03	0–60	0.05	0–60	0.03	0–120	0.01	1993–2278	0.13	370–670	0.01	0–0	0.00	0.04	CN15	
► *Short triangle stepped margin*	T	49–110	0.25	0–60	0.13	0–60	0.50	220–330	0.25	0–1148	0.13	370–670	0.50	11197–12148	0.06	0.26	CN15	
Long rectangular with striations	T	49–110	0.25	0–60	0.25	0–60	0.25	0–120	0.25	0–0	0.00	1240–1540	0.25	0–0	0.00	0.25	CN15	
Triangle hooked margin	T	49–110	0.13	0–60	0.13	60–160	0.06	0–120	0.13	2278–3329	0.13	670–970	0.06	11197–12148	0.06	0.10	CN15	Pliocene/ Quaternary
Curved triangle pointed margin	T	150–218	0.06	0–60	0.06	0–60	0.25	220–330	0.06	3329–3589	0.06	670–970	0.06	0–0	0.00	0.09	CN15	
Long triangle stepped margin	T	49–110	0.25	260–330	0.25	60–160	0.25	230–330	0.13	1148–1580	0.13	0–370	0.25	0–9246	0.13	0.20	CN15	
Large with numerous lines	T	250–303	0.06	0–60	0.06	60–160	0.06	0–120	0.06	2768–3329	0.13	670–970	0.06	13039–14017	0.13	0.08	CN15	
Triangle sinuous inline	T	350–408	0.25	60–160	0.13	60–160	0.25	120–220	0.25	1148–1328	0.25	1240–1540	0.13	9256–10248	0.13	0.20	CN15–13	
Two triangles	T	49–110	0.13	0–60	0.25	160–260	0.25	220–330	0.13	1993–2278	0.13	670–970	0.13	0–0	0.00	0.17	CN15	
Pointed triangle long margins	T	350–408	0.01	0–60	0.03	0–60	0.01	0–120	0.01	2768–3329	0.01	2490–2790	0.03	15132–15330	0.01	0.02	CN12–10	
Triangle concave first margin	B	648–694	0.01	140–240	0.05	40–140	0.05	100–200	0.03	3319–3579	0.01	3130–3430	0.01	10238–11187	0.01	0.02	CN19–17	
Narrow triangle ragged base	B	595–648	0.01	240–310	0.05	140–240	0.03	100–200	0.01	2268–3319	0.01	2180–2480	0.01	0–0	0.00	0.02	CN10	
► *Long triangle short inline*	T	607–650	0.50	60–160	0.50	60–160	0.50	120–220	0.50	2278–3329	0.50	2490–2790	0.25	11197–12148	0.25	0.43		
► *Rectangular saw-toothed*	T	0–49	0.13	0–60	0.25	160–260	1.00	120–220	0.50	2278–3329	0.13	370–670	0.13	12148–13039	0.13	0.32	CN15	
Stippled triangle	T	49–110	0.13	0–0	0.00	0–0	0.00	330–420	0.13	0–0	0.00	670–970	0.01	12148–13039	0.13	0.10	CN15	
Triangle with base angle	T	450–509	0.06	160–260	0.06	160–260	0.13	220–330	0.13	1993–2278	0.06	370–670	0.06	13039–14017	0.06	0.08	CN15	
Triangle irregular base	B	493–548	0.06	140–240	0.13	140–240	0.25	100–200	0.06	2268–3319	0.06	2780–3130	0.50	0–0	0.00	0.18	CN7–4	
Short rectangular with striations	B	850–894	0.25	0–0	0.00	140–240	0.50	400–485	0.13	2278–3329	0.25	2180–2480	0.25	14007–15122	0.13	0.25	CN5	
► *Long ellipse*	B	648–694	0.13	140–240	0.50	160–260	1.00	100–200	0.50	3319–3579	0.13	2780–3130	0.25	12138–13029	0.13	0.38	CN7	
Small dendritic few radiating lines	T	49–110	0.01	260–330	0.03	160–260	0.01	220–330	0.01	2278–3329	0.25	2490–2790	0.03	15133–15330	0.01	0.05	CN15	
► *Broad triangle parallel inline*	T	750–809	0.25	160–260	0.25	160–260	0.25	0–120	0.25	2368–3329	0.50	3140–3440	0.25	15128–15326	0.25	0.29	CN7–4	
Long rectangular with striations	B	798–850	0.25	140–240	0.25	240–340	0.25	200–310	0.25	0–0	0.00	2780–3130	0.13	0–0	0.00	0.19	CN5	
Small circular center	T	550–607	0.06	330–400	0.06	160–260	0.06	330–420	0.06	0–0	0.00	0–0	0.00	0–0	0.00	0.06	CN12	
Long triangle stepped margin	B	595–648	0.25	240–310	0.25	340–410	0.25	310–400	0.01	2268–3319	0.13	2780–3130	0.25	13029–14007	0.13	0.18	CN7	
Triangle with triangular projection	T	607–650	0.13	160–260	0.25	360–430	0.13	330–420	0.13	1319–1580	0.25	370–670	0.13	14017–15132	0.50	0.21	CN15	
Small dendritic many radiating lines	T	650–706	0.06	260–330	0.13	260–360	0.06	0–120	0.06	2278–3329	0.13	2790–3190	0.13	0–0	0.00	0.09	CN15	
Stippled triangle	B	798–850	0.13	0–0	0.00	0–0	0.00	310–400	0.13	0–0	0.00	960–1230	0.13	13029–14007	0.13	0.13	CN1	
Circular with line across	B	850–894	0.13	310–380	0.06	0–0	0.00	200–310	0.50	2278–3329	0.13	3130–3430	0.13	14007–15122	0.06	0.17	CN7	
Triangle sinuous inline	B	798–850	0.25	140–240	0.13	340–410	0.25	310–400	0.25	2278–3329	0.25	3430–3730	0.13	12138–13029	0.13	0.20	CN1	
Wide triangle	T	852–906	0.01	260–330	0.01	260–360	0.01	330–420	0.01	2278–3329	0.03	2790–3140	0.03	14017–15123	0.01	0.02	CN15	Miocene
Triangle transverse line across	T	852–906	0.06	260–330	0.06	260–360	0.06	220–330	0.13	3324–3589	0.13	2790–3140	0.06	15123–15330	0.06	0.08	CN10	
► *Elliptical with line across*	B	894–995	0.13	310–380	0.25	340–410	0.25	310–400	0.50	2268–3319	0.50	3130–3430	0.50	12138–13039	0.13	0.32	CN7	
Asymmetrical peak depression	T	852–906	0.05	60–160	0.01	260–360	0.01	330–420	0.03	3329–3589	0.01	3140–3440	0.01	0–0	0.00	0.02	CN9	
Triangle short wing	T	809–852	0.06	260–330	0.25	260–360	0.25	330–420	0.13	2278–3329	0.13	3140–3440	0.13	14017–15123	0.13	0.15	CN8	
► *Long triangle short inline*	B	748–798	0.25	240–310	1.00	340–410	1.00	400–485	0.13	3319–3579	0.50	3430–3730	0.25	12138–13029	0.13	0.46		
Triangle sigmoid	T	0–49	0.13	260–330	0.25	260–360	0.13	420–505	0.13	3329–3584	0.50	3440–3740	0.25	13039–14017	0.13	0.21	CN15	
Triangle with parallel inline	T	0–49	0.03	260–330	0.05	360–430	0.05	330–420	0.01	0–0	0.00	0–0	0.00	15123–15330	0.01	0.02	CN15	
Triangle double flex	T	852–906	0.13	0–0	0.00	360–430	0.25	330–420	0.25	3949–4238	0.13	3140–3440	0.25	14017–15123	0.13	0.16	CN2	
Triangle pointed margin ends	T	1215–1250	0.25	260–330	0.06	260–360	0.13	420–505	0.06	3589–3949	0.13	1240–1540	0.06	15415–15764	0.25	0.13	CN2	
Flexed triangle shallow inbase ≥ 120	T	750–809	0.13	260–330	0.13	360–430	0.25	752–795	0.25	3329–3589	0.13	3140–3440	0.50	0–0	0.00	0.23	CN2	
Triangle medium wing	T	852–906	0.50	260–330	0.50	360–430	0.25	0–120	0.06	2278–3329	0.13	3140–3440	0.13	14015–15128	0.13	0.24	CN5	
► *Short triangle stepped margin*	B	995–1048	0.25	310–380	0.13	410–490	0.50	400–485	0.50	2268–3319	0.50	3430–3730	0.25	12138–13029	0.13	0.32	CN1	
► *Two triangles*	B	1048–1103	0.13	310–380	0.50	410–490	0.50	310–400	0.13	3319–3579	0.13	3430–3730	0.25	0–0	0.00	0.27	CN2	
► *Small triangle long striations*	B	894–995	0.13	310–380	1.00	410–490	0.50	485–650	0.50	3319–3579	1.00	3430–3730	0.50	15320–15409	0.50	0.59	CN1	
Triangle with base angle	B	1200–1250	0.06	570–650	0.13	600–720	0.13	737–775	0.50	3319–3579	0.13	3430–3730	0.06	15409–15758	0.25	0.18	CP14	
Pointed triangle short inline	T	650–706	0.01	260–330	0.03	510–620	0.01	752–795	0.03	0–0	0.00	3440–3740	0.10	0–0	0.00	0.03	CP18	

Small circular center	B	1150–1200	0.13	380–470	0.06	240–340	0.06	880–980	0.06	0–0	0.00	0–0	0.00	0–0	0.00	0.08	CP19	
Small dendritic few radiating lines	B	1350–1394	0.06	380–470	0.25	410–490	0.50	880–980	0.13	3319–3579	0.13	3730–4080	0.13	15409–15758	0.06	0.18	CN2	
► *Rectangular saw-toothed*	B	1103–1150	0.13	380–470	1.00	720–830	0.50	650–737	0.13	3319–3579	0.13	3730–4080	0.25	15122–15320	0.50	0.38	CN2	
Curved triangle pointed margin	B	894–995	0.06	470–570	0.25	720–830	0.25	485–650	0.06	0–0	0.00	3730–4080	0.06	0–0	0.00	0.14	CP17	
Triangle with high inline apex	B	1150–1200	0.06	570–650	0.06	490–600	0.25	650–737	0.13	2268–3529	0.25	3730–4080	0.13	15320–15409	0.06	0.13	CP17	
Triangle with canals	T	250–303	0.01	490–590	0.03	620–740	0.03	670–752	0.03	2278–3329	0.01	0–0	0.00	0–0	0.00	0.02	CN15	
Small dendritic many radiating lines	B	1103–1150	0.13	660–760	0.06	830–930	0.06	980–1080	0.06	3319–3579	0.13	3430–3730	0.25	0–0	0.00	0.14	CP15	
Tanged triangle	T	809–850	0.06	490–590	0.13	950–1040	0.06	900–1000	0.25	4248–4528	0.25	4090–4390	0.13	16060–16215	0.06	0.13	CP18	
Triangle inward angle	T	750–809	0.03	490–590	0.01	0–0	0.00	1000–1100	0.01	0–0	0.00	3740–4090	0.01	0–0	0.00	0.01	CN2	
Large with numerous lines	B	1103–1150	0.13	470–570	0.06	830–930	0.06	650–737	0.06	3319–3579	0.13	4080–4380	0.13	15320–15409	0.13	0.10	CP17	
Triangle inward angle	B	1103–1150	0.05	570–660	0.01	0–0	0.00	1080–1180	0.01	0–0	0.00	4080–4380	0.01	0–0	0.00	0.01	CP14	Oligocene
Asymmetrical peak depression	B	1288–1350	0.01	570–660	0.03	340–410	0.01	775–880	0.01	3579–3949	0.01	3430–3730	0.01	0–0	0.00	0.01	CP14	
► *Flexed triangle shallow inbase ≥ 120*	B	1200–1250	0.25	570–660	0.25	490–600	0.50	775–880	0.25	3579–3949	0.13	4080–4580	0.50	0–0	0.00	0.31	CP17	
Pointed triangle long margins	B	1288–1350	0.03	660–760	0.01	720–830	0.01	775–880	0.01	3319–3579	0.01	3430–3730	0.03	15320–15409	0.01	0.02	CP14–11	
► *Rounded apex triangle*	B	1250–1288	0.25	660–760	0.50	490–600	0.50	980–1080	0.13	3579–3949	1.00	4080–4380	0.25	15409–15758	1.00	0.52	CP16	
Triangle with parallel inline	B	1350–1394	0.01	470–570	0.03	600–720	0.05	650–737	0.03	0–0	0.00	0–0	0.00	15409–15758	0.01	0.02	CP16	
Five peaks flared base	T	1252–1288	0.13	0–0	0.00	0–0	0.00	1000–1100	0.13	0–0	0.00	3440–3740	0.06	16060–16215	0.06	0.09	CP17	
Triangle concave base	T	1252–1300	0.06	570–680	0.13	850–950	0.13	670–752	0.06	4248–4528	0.06	3740–4090	0.13	16064–16219	0.25	0.12	CP11	
Pointed triangle short inline	B	1288–1350	0.05	310–380	0.03	930–1020	0.01	775–880	0.03	0–0	0.00	4080–4380	0.03	0–0	0.00	0.03	CP11–6	
► *Triangle sigmoid*	B	1394–1450	0.13	650–760	0.50	340–410	0.13	1080–1180	0.13	4518–4698	0.25	4080–4380	0.50	16209–16696	0.25	0.31	CP12	
Triangle with canals	B	1288–1350	0.05	660–760	0.05	930–1020	0.01	1180–1204	0.05	0–0	0.00	4080–4380	0.03	0–0	0.00	0.04	CP13	
Triangle curved base	T	1452–1483	0.50	0–0	0.00	0–0	0.00	0–0	0.00	4789–4938	0.06	4700–5040	0.06	16064–16215	0.13	0.19	CP11	Eocene
Triangle double flex	B	1483–1540	0.13	0–0	0.00	720–830	0.13	1204–1220	0.13	4238–4518	0.13	4080–4380	0.03	0–0	0.00	0.11	CP13	
Broad triangle parallel inline	B	1483–1850	0.50	960–990	0.13	1020–1050	0.13	1180–1204	0.25	4698–4779	0.25	4380–4690	0.25	16209–16696	0.13	0.23	CP14–11	
Flexed triangle asymmetric	T	1652–1708	0.25	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0.25		
Narrow straight triangle	T	1652–1708	0.06	0–0	0.00	0–0	0.00	0–0	0.00	4248–4528	0.06	4700–5040	0.13	16703–16926	0.13	0.09		
Triangle hooked margin	B	1691–1750	0.13	860–960	0.13	930–1020	0.13	1180–1204	0.13	4698–4779	0.13	4690–5030	0.06	15409–15758	0.13	0.12	CN1	
► *Triangle radiating inline*	T	1652–1708	0.13	0–0	0.00	0–0	0.00	0–0	0.00	4708–4789	0.25	4700–5040	0.25	16229–17009	0.50	0.28	CP7–6	
Prominence with wye-line	T	1498–1540	0.01	0–0	0.00	0–0	0.00	0–0	0.00	5088–5238	0.13	4700–5040	0.25	16703–16926	0.13	0.17	CP6	
Prominent polygon	T	1708–1752	0.25	0–0	0.00	0–0	0.00	0–0	0.00	4789–4938	0.13	4700–5040	0.50	16703–16926	0.13	0.25	CP6	
Narrow triangle unequal margins	T	1708–1752	0.13	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0.13		
Giant lanceolate	T	1952–1995	0.01	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	4700–5040	0.03	0–0	0.00	0.02	CP18	
Wide triangle	B	1893–1950	0.01	310–380	0.01	0–930	0.01	1180–1204	0.01	0–0	0.00	5030–5330	0.01	16209–16702	0.01	0.01	CP11–6	
Tanged triangle	B	1483–1995	0.13	860–960	0.25	1020–1050	0.06	1180–1204	0.25	4698–4779	0.06	5030–5330	0.25	16696–16920	0.13	0.16	CP11	
Triangle transverse line across	B	1789–1850	0.25	960–990	0.13	1180–1204	0.25	1180–1204	0.25	5078–5228	0.25	5030–5330	0.25	16054–16209	0.06	0.21	CP2	
Triangle short wing	B	1850–1893	0.06	960–990	0.25	1180–1204	0.25	1180–1204	0.25	4698–4779	0.25	5030–5330	0.50	16920–17009	0.13	0.24	CP12–2	
Beveled triangle mid inline	T	1850–1912	0.13	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0.13		
Short triangle bowed inline	T	1852–1912	0.25	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	16926–17015	0.13	0.19		
Flexed triangle asymmetric	B	1893–1950	0.13	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0.13		
Narrow triangle unequal margins	B	1893–1950	0.06	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0.06		
Narrow straight triangle	B	1893–1950	0.25	0–0	0.00	0–0	0.00	0–0	0.00	4698–4779	0.06	5030–5330	0.13	16920–17015	0.13	0.14		Paleocene
Triangle curved base	B	1990–2040	0.06	0–0	0.00	0–0	0.00	0–0	0.00	5078–5228	0.06	5030–5330	0.06	16229–17009	0.13	0.08	CP2	
► *Triangle radiating inline*	B	1893–1950	0.25	0–0	0.00	0–0	0.00	0–0	0.00	5078–5228	0.50	5030–5330	0.25	17009–17010	0.50	0.38	CP4–3	
► *Triangle concave base*	B	1950–1995	0.13	960–990	0.25	930–1020	0.13	1204–1220	0.13	5078–5228	0.50	5030–5330	0.50	17009–17010	0.25	0.27	CP6–3	
Triangle modified margin ends	T	1912–1952	0.06	0–0	0.00	0–0	0.00	0–0	0.00	5088–5238	0.06	0–0	0.00	16702–16926	0.13	0.08	CP1–2	
► *Triangle pointed margin ends*	B	1995–2040	0.13	960–990	0.25	1020–1050	0.25	1204–1220	0.25	5078–5228	0.50	5030–5330	0.25	16229–17009	0.50	0.30	CP4–3	
► *Triangle medium wing*	B	1893–1950	0.13	960–990	0.50	1020–1050	0.25	1204–1220	0.25	5078–5228	0.50	5030–5330	0.13	17009–17010	0.50	0.32	CP2	
Giant lanceolate	B	1995–2040	0.01	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	5030–5330	0.03	0–0	0.00	0.01	CP6–3	
► *Beveled triangle concave margins*	T	1708–1752	0.13	0–0	0.00	0–0	0.00	0–0	0.00	5088–5238	0.25	5040–5340	0.50	16703–16929	0.25	0.28	CP4–5	
► *Beveled triangle concave margins*	B	1950–1995	0.13	0–0	0.00	0–0	0.00	0–0	0.00	5228–5440	1.00	5330–5630	0.50	16920–17009	0.25	0.47	CP4–3	
Beveled triangle mid inline	B	1995–2040	0.13	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0.13	CP1	
► *Triangle modified margin ends*	B	1995–2040	0.25	0–0	0.00	0–0	0.00	0–0	0.00	5228–5440	1.00	0–0	0.00	16920–17009	0.13	0.46	CP1	
► *Triangle with triangular projection*	B	1995–2040	0.13	960–990	1.00	1020–1050	0.25	1204–1220	0.50	5228–5440	1.00	5030–5330	0.50	16929–17009	0.50	0.55	CP2	
Short triangle bowed inline	B	1995–2040	0.13	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	17009–17010	0.13	0.13	CP4–3	
► *Spiky palmate*	T	2008–2040	0.25	0–0	0.00	0–0	0.00	0–0	0.00	5238–5450	0.06	5340–5640	0.50	0–0	0.00	0.27		
► *Triangle smooth surface*	T	2008–2040	1.00	0–0	0.00	0–0	0.00	0–0	0.00	5238–5450	0.06	5340–5640	1.00	0–0	0.00	0.69		
► *Wide triangle projection*	T	2042–2060	0.25	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	5340–5640	0.50	0–0	0.00	0.38		
Centrally striated triangle	T	2042–2060	0.06	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	5340–5640	0.13	0–0	0.00	0.10		Cretaceous
► *Triangle long inline*	T	2042–2060	0.13	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	5340–5640	0.50	0–0	0.00	0.32		
Triangle square inline	T	2042–2060	0.13	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	5340–5640	0.25	0–0	0.00	0.19		
Striated blunt triangle	T	2042–2060	0.06	0–0	0.00	0–0	0.00	0–0	0.00	0–0	0.00	5340–5640	0.25	0–0	0.00	0.16		

Note: T indicates latest occurrence of subtype and B the earliest occurrence. The levels in the cores between which an event occurs are in centimeters under the headings "Up" and "Lo." The reliability index (see text) for each event is listed under "Rel," the mean of the reliability scores under "Rel. mean." Events with a reliability score greater than 0.25 are designated by an arrow (►). The nannofossil zone in which the subtype first or last appears in Pacific samples containing other microfossils is shown on the right (based on all previously published co-occurrences of ichthyoliths and nannofossils). For the procedure to determine epoch boundaries, see text.

transverse line absent, a simply curved line terminating at margins at same level. Lateral shadows absent. Overall length 130–650 μm, maximum width 100–400 μm.

Distinction from similar forms: *Beveled triangle concave margins* is readily distinguished by its concave, beveled margins, pointed apex (in a few specimens, such as that illustrated on Plate 1, Fig. 11, the apex is rounded), and lack of lateral shadows.

Occurrence: In late Paleocene (nannofossil Zone CP6) at Site 577. Restricted to Paleocene in sequences correlated by means of ichthyoliths (see Table 4).

LIST OF TAXA USED

Listed below, in alphabetical order, by colloquial name, are the ichthyolith subtypes identified in this study, with bibliographic references to indicate the current concept of each taxon.

Asymmetrical peak depression: Gottfried et al., 1984
Beveled triangle concave margins: new subtype
Beveled triangle mid inline: Doyle et al., 1978
Broad triangle parallel inline: Gottfried et al., 1984
Centrally striated triangle: Doyle et al., 1978
Circular with line across: Doyle et al., 1974; emend. Doyle and Riedel, 1979a
Curved triangle pointed margin: Doyle et al., 1974; emend. Doyle and Riedel, 1979a
Curved triangle inline constricted: Doyle et al., 1974
Elliptical with line across: Doyle et al., 1974; emend. Edgerton et al., 1977
Five peaks flared base: Doyle et al., 1974
Flexed triangle asymmetric: new subtype
Flexed triangle shallow inbase: Doyle et al., 1974
Flexed triangle shallow inbase ≥ 120: Dunsworth et al., 1975; emend. Edgerton et al., 1977
Giant lanceolate: Doyle et al., 1974
Large with numerous lines: Doyle et al., 1974
Long ellipse: Gottfried et al., 1984
Long rectangular with striations: Doyle et al., 1974
Long triangle short inline: Gottfried et al., 1984
Long triangle stepped margin: Doyle et al., 1974; emend. Edgerton et al., 1977
Narrow straight triangle: new subtype
Narrow triangle cross-hachured: Doyle et al., 1974
Narrow triangle ragged base: Dunsworth et al., 1975
Narrow triangle sharply pointed: Gottfried et al., 1984
Narrow triangle straight inbase: Doyle et al., 1974
Narrow triangle unequal margins: new subtype
Narrower crescent: Doyle et al., 1978
Plain and lined lanceolate: Doyle et al., 1974; emend. Doyle et al., 1978
Pointed and skirted: Doyle et al., 1978
Pointed triangle long margins: Gottfried et al., 1984
Pointed triangle short inline: Gottfried et al., 1984
Prominence with wye-line: Doyle et al., 1978
Prominent polygon: Doyle et al., 1978
Rectangular saw-toothed: Doyle et al., 1974; Dunsworth et al., 1975; Doyle and Riedel, 1979a
Rounded apex triangle: Doyle et al., 1974
Short rectangular with striations: Doyle et al., 1974
Short triangle bowed inline: Doyle et al., 1978
Short triangle stepped margin: Doyle et al., 1974; emend. Edgerton et al., 1977
Small circular center: Doyle et al., 1974
Small dendritic few radiating lines: Doyle et al., 1974
Small dendritic many radiating lines: Doyle et al., 1974
Small triangle crenate margin: Dunsworth et al., 1975; emend. Doyle and Riedel, 1979a
Small triangle long striations: Dunsworth et al., 1975; Kaneps et al., 1981
Spiky palmate: Doyle and Riedel, 1980
Stippled triangle: Dunsworth et al., 1975
Striated blunt triangle: Doyle et al., 1978
Tanged triangle: Gottfried et al., 1984
Triangle broad wing: Doyle et al., 1974; emend. Edgerton et al., 1977
Triangle concave base: Dunsworth et al., 1975
Triangle concave first margin: Gottfried et al., 1984
Triangle curved base: Doyle et al., 1978
Triangle curved pointed margins: new subtype
Triangle double flex: Dunsworth et al., 1975; emend. Doyle and Riedel, 1979a
Triangle double inline: Gottfried et al., 1984
Triangle hooked margin: Doyle et al., 1974
Triangle inward angle: Gottfried et al., 1984
Triangle inline halfway: Doyle et al., 1974
Triangle irregular base: Gottfried et al., 1984
Triangle long inline: Doyle et al., 1978
Triangle medium wing: Doyle et al., 1974
Triangle modified margin ends: new subtype
Triangle one canal above: Doyle et al., 1974
Triangle pointed margin ends: Doyle et al., 1974; emend. Doyle and Riedel, 1979a
Triangle radiating inline: new subtype
Triangle short wing: Doyle et al., 1974
Triangle sigmoid: Dunsworth et al., 1975; emend. Edgerton et al., 1977
Triangle sigmoid rough: Ramsey et al., 1976
Triangle sinuous inline: Gottfried et al., 1984
Triangle square inline: Doyle et al., 1978; emend. Edgerton et al., 1977
Triangle smooth surface: Doyle and Riedel, 1980
Triangle transverse line across: Doyle et al., 1974; emend. Doyle and Riedel, 1979a
Triangle with canals: Doyle et al., 1974
Triangle with base angle: Dunsworth et al., 1975
Triangle with high inline apex: Doyle et al., 1974
Triangle with parallel inline: Doyle et al., 1974
Triangle with triangular projection: Doyle et al., 1974
Triangular toothed: Doyle et al., 1978
Two triangles: Doyle et al., 1974
Wide triangle: Dunsworth et al., 1975; emend. Doyle and Riedel, 1979a
Wide crescent: Doyle et al., 1978
Wide triangle projection: Doyle et al., 1978
Wide triangle straight inbase: Doyle et al., 1974

ACKNOWLEDGMENTS

This research was supported partly by Contract 26-6608 from Sandia National Laboratories and NSF Grant OCE82-14587 and partly by the University of California.

Hans Thierstein and an anonymous reviewer reviewed the manuscript and made suggestions that improved it. M. J. Westberg provided the computer program used to determine the most probable order of the biostratigraphic events. Susan Green and Elaine Winfrey helpfully assisted in various aspects of the work. The frequently frustrating task of entering and retrieving the text from the CATT computer system was accomplished by Carol Pittman.

REFERENCES

Blank, R. G., and Ellis, C. H., 1982. The probable range concept applied to the biostratigraphy of marine microfossils. *J. Geol.*, 90: 415–433.

Corliss, B. H., Hollister, C. D., et al., 1982. A paleoenvironmental model for Cenozoic sedimentation in the central North Pacific. *In* Scrutton, R., and Talwani, M. (Eds.), *The Ocean Floor:* New York (Wiley), pp. 277–304.

Doyle, P. S., Dunsworth, M. J., and Riedel, W. R., 1977. Reworking of ichthyoliths in eastern tropical Pacific sediments. *Deep-Sea Res.*, 24:181–198.

________, 1978. Ichthyoliths from some southeast Atlantic sediments, DSDP Leg 40. *In* Bolli, H. M., Ryan, W. B. F., et al., *Init. Repts. DSDP*, Suppl. to Vols. 38, 39, 40, and 41: Washington (U.S. Govt. Printing Office), 743–759.

Doyle, P. S., Kennedy, G. G., and Riedel, W. R., 1974. Stratignathy. *In* Davies, T. A., Luyendyk, B. P., et al., *Init. Repts. DSDP*, 26: Washington (U.S. Govt. Printing Office), 825–905.

Doyle, P. S., and Riedel, W. R., 1979a. Ichthyoliths: Present status of taxonomy and stratigraphy of microscopic fish skeletal debris. Scripps Institution of Oceanography Reference Series, Number 79-

16. National Technical Information Service (Publications), Springfield, Virginia 22161, pp. 1-231.

———, 1979b. Cretaceous to Neogene ichthyoliths in a giant piston core from the central North Pacific. *Micropaleontology*, 25: 337-364.

———, 1980. Ichthyoliths from Site 436, Northwest Pacific, Leg 56, Deep Sea Drilling Project. *In* Scientific Party, *Init. Repts. DSDP*, 56, Pt. 2: Washington (U.S. Govt. Printing Office), 887-893.

———, 1981. Ichthyoliths at Site 464 in the Northwest Pacific, Deep Sea Drilling Project Leg 62. *In* Thiede, J., Vallier, T. L., et al., *Init. Repts. DSDP*, 62: Washington (U.S. Govt. Printing Office), 491-494.

Dunsworth, M. J., Doyle, P. S., and Riedel, W. R., 1975. Ichthyoliths from some NW Pacific Sediments, DSDP Leg 32. *In* Larson, R. L., Moberly, R., et al., *Init. Repts. DSDP*, 32: Washington (U.S. Govt. Printing Office), 853-864.

Edgerton, C. C., Doyle, P. S., and Riedel, W. R., 1977. Ichthyolith age determinations of otherwise unfossiliferous Deep Sea Drilling Project cores. *Micropaleontology*, 23:194-205.

Gottfried, M. D., Doyle, P. S., and Riedel, W. R., 1984. Advances in ichthyolith stratigraphy of the Pacific Neogene and Oligocene. *Micropaleontology*, 30:71-85.

———, 1985. Stratigraphic interpretations of pelagic sequences revised on the basis of ichthyoliths. *Micropaleontology*, 30:426-444.

Hay, W. W., 1972. Probabilistic stratigraphy. *Eclogae Geol. Helv.*, 65: 255-266.

Kaneps, A. G., Doyle, P. S., and Riedel, W. R., 1981. Further ichthyolith age determinations of otherwise unfossiliferous Deep Sea Drilling Project cores. *Micropaleontology*, 27:317-331.

Okada, H., and Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Mar. Micropaleontol.*, 5: 321-325.

Ramsey, C. A., Doyle, P. S., and Riedel, W. R., 1976. Ichthyoliths in late Mesozoic pelagic sediments, mainly from Italy. *Micropaleontology*, 22:129-142.

Riedel, W. R., 1981. DSDP biostratigraphy in retrospect and prospect. *Spec. Publ. Soc. Econ. Paleontol. Mineral.*, 32:253-315.

Riedel, W. R., and Westberg, M. J., 1982. Neogene radiolarians from the eastern tropical Pacific and Caribbean, DSDP Leg 68. *In* Prell, W. L., Gardner, J. V., et al., *Init. Repts. DSDP*, 68: Washington (U.S. Govt. Printing Office), 289-300.

Westberg, M. J., and Riedel, W. R., 1982. Radiolarians from the Middle America Trench off Guatemala, DSDP Leg 67. *In* Aubouin, J., von Huene, R., et al., *Init. Repts. DSDP*, 67: Washington (U.S. Govt. Printing Office), 401-424.

Date of Initial Receipt: 21 February 1984
Date of Acceptance: 21 May 1984

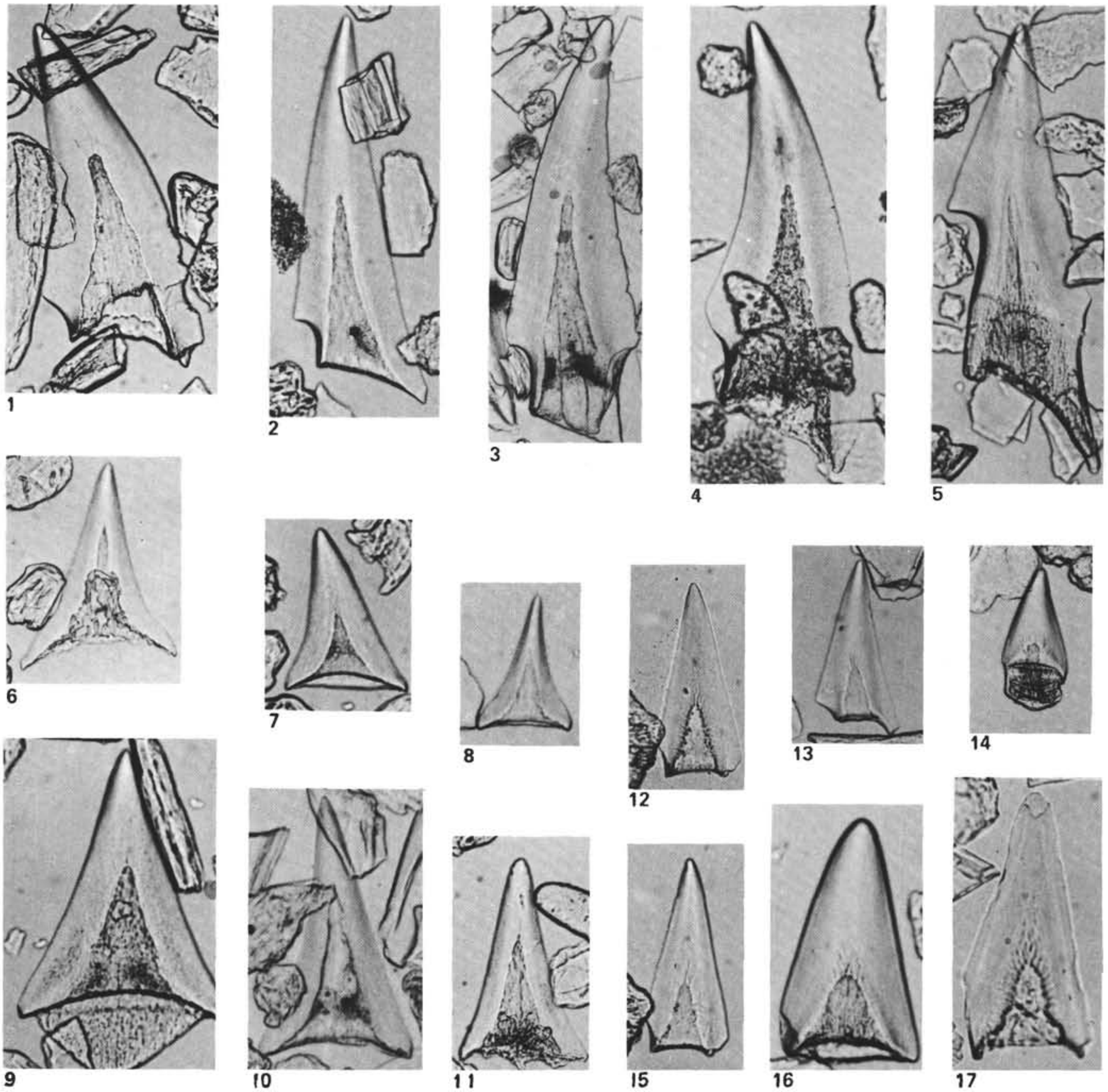

Plate 1. Paleocene and early Eocene taxa described herein from DSDP Leg 86 and GPC-3 sequences. Magnifications are ×120, unless otherwise indicated. In the explanations to the figures, the sample numbers and slide designations (in the form "Sl.5", etc.) indicate preparations in our collection at Scripps Institution of Oceanography, and designations in the form "P48" indicate England Finder positions of the illustrated specimens on the slides. **1–5.** *a8/b1,5/c1/d1/e0/f23-38/g2/h2* new subtype. *Flexed triangle asymmetric.* (1) GPC-3, 1789–1811 cm, Sl.5, F31. (2) DSDP 576B-6-2, 100–150 cm, Sl.63-1, C29. (3) DSDP 576B-6-2, 100–150 cm, Sl.63-1, H16. (4) GPC-3, 1789–1811 cm, Sl.1, C8. (5) DSDP 576B-6-2, 100–150 cm, Sl.63-3, M19. Type specimen. **6–11.** *a9/b1,5/c13/d13/e1/f1/g1/h0,5/i6,7/j6,7/k3,8,14/m0.25–0.60/n1.3–2.0/p0/q0,2,6/r0,1,3/s1,2/t1/z4/cc0/dd0/ee0/ff0/gg0/hh0/jj2/kk2/mm0/nn0* new subtype. *Beveled triangle concave margins.* (6) DSDP 578-19-2, 140–150 cm, Sl.63-1, L27. (7) DSDP 576-7-6, 68–74 cm, Sl.63-3, Y33. (8) DSDP 576A-6-3, 140–150 cm, Sl.63-6, J45. (9) DSDP 576-7-6, 68–74 cm, Sl.63-3, R38. Type specimen. (10) DSDP 576B-6-2, 100–150 cm, Sl.63-1, M26. (11) DSDP 576-7-6, 68–74 cm, Sl.63-3, Q34. **12–17.** *a9/b1,5/c1,13/d1/e1/f21/g1/h0,4,5/i2/j2/k7,8/m0.40–0.75/n1.0–2.2/p1.0–2.4/q0,2,3,6/r0,1,2/s1,2/t1/z1,4/cc0/dd0/ee0/ff0/gg0/hh0/jj2/kk2/mm0/nn0* new subtype. *Triangle radiating inline.* (12) GPC-3, 1789–1811 cm, Sl.2, P23. Type specimen. (13) DSDP 577-10-3, 31–39 cm, Sl.63-3, N29. (14) GPC-3, 1850 cm, Sl.3, Q49. (15) GPC-3, 1789–1811 cm, Sl.2, P23. (16) GPC-3, 1893–1912 cm, Sl.1, C29. (17) DSDP 576-7-5, 68–74 cm, Sl.63-1, K24, ×200.

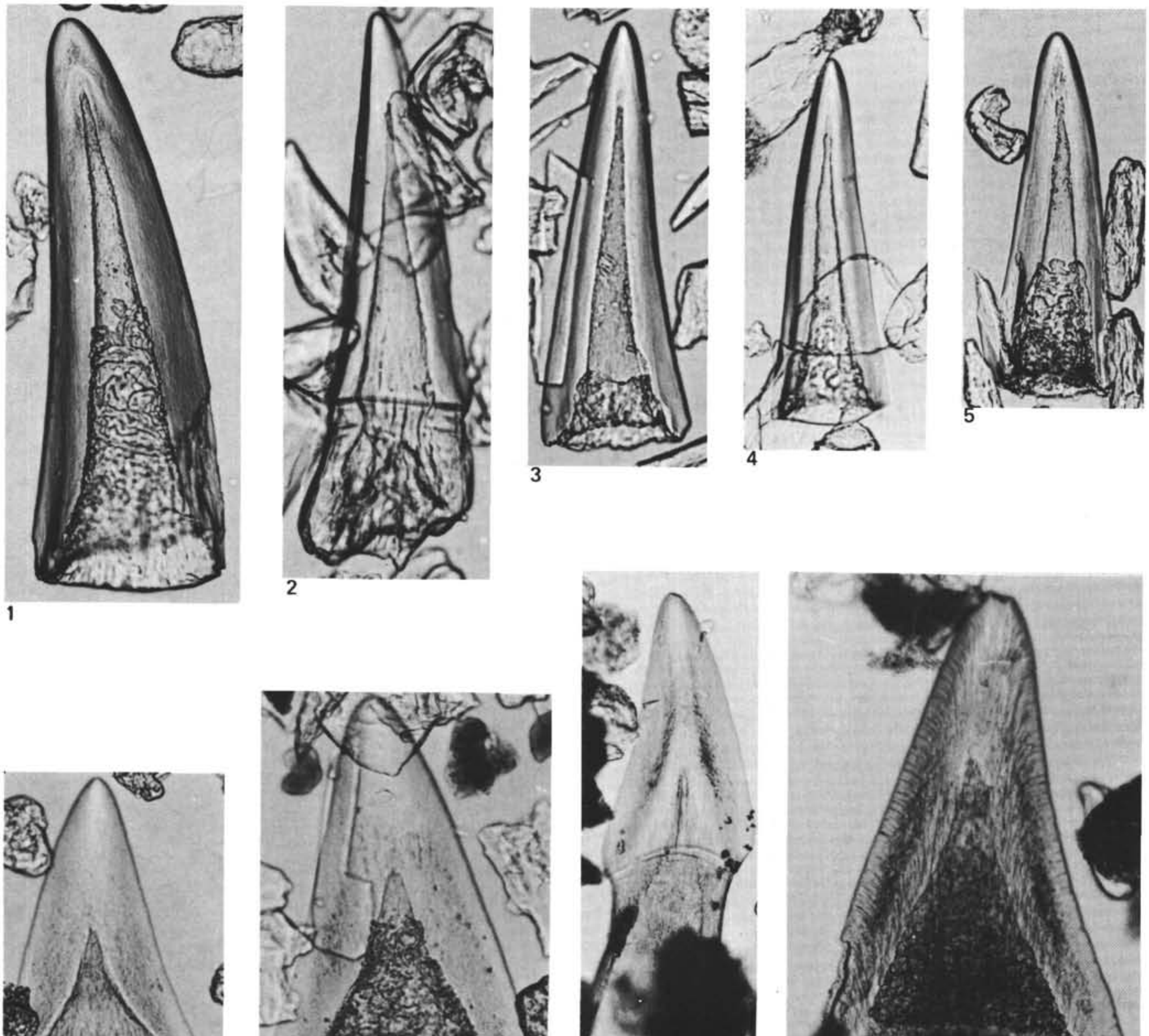

Plate 2. Magnifications are ×120. **1–5.** *a9/b1,5/c1/d1/e1/f4/g1/h0,5/i2,6/j2,3/k8/m0.14–0.25/n2.5–3.0/p0/q0,2/r0,1/s1/t1/z2/cc0/dd0/ee0/ff0/gg0/hh0/jj2/kk2/mm0/nn0* new subtype. *Narrow straight triangle.* (1) GPC-3, 1789–1811 cm, Sl.5, C12. (2) DSDP 578-19-2, 140–150 cm, Sl.63-1, U17. Type specimen. (3) GPC-3, 1789–1811 cm, Sl.5, F31. (4) GPC-3, 1789–1811 cm, Sl.1, M40. (5) DSDP 576-7-6, 59–65 cm, Sl.63-2, J42. **6–9.** *a9/b1,5/c1,13/d1,13/e1/f1/g1/h0,5/i6/j2,3/k3,14/m0.35–0.75/n1.3–2.0/p0/q0,2,6,7/r0,1/s1/t1/z4/cc0/dd0/ee0/ff0/gg0/hh0/jj2/kk2/mm0/nn0* new subtype. *Triangle modified margin ends.* (6) GPC-3, 1995–2008 cm, Sl.7, V48. (7) GPC-3, 1995–2008 cm, Sl.7, H42. (8) DSDP 577-11-6, 31–39 cm, Sl.63-1, V39. Type specimen. (9) DSDP 577-12-3, 82–90 cm, Sl.63-1, W39.

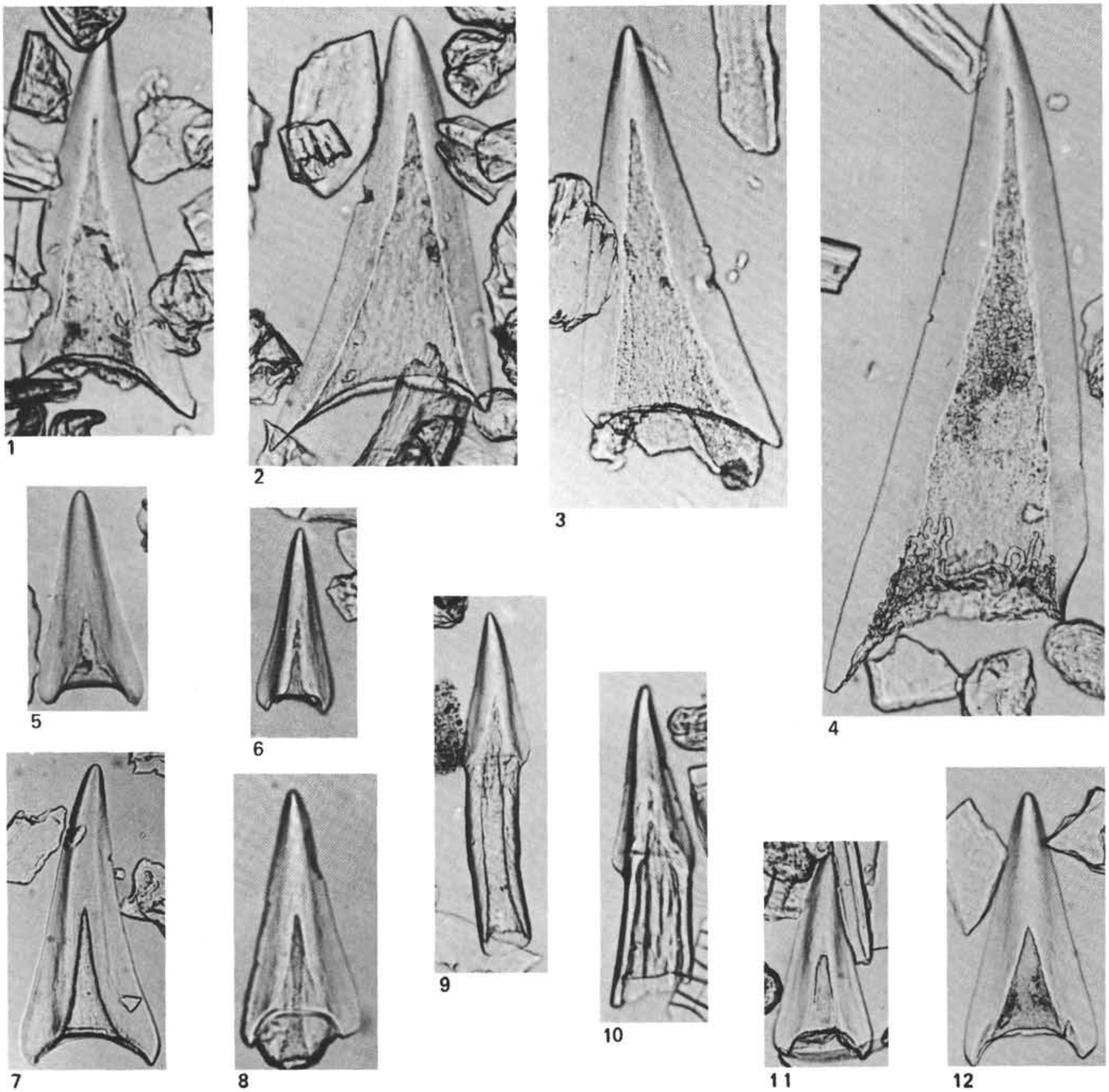

Plate 3. Magnifications are ×120. **1–4.** *a9/b1,5/c13/d1,13/e1/f1/g1/h0,3,4/i2,3/j6/k8/m0.1–0.4/n1.8–2.5/p2.2–2.6/q0,6/r0,1,2,3/s1,2/t1/z9/cc0/dd0/ee0/ff0/gg0/hh0/jj0/kk0/mm0/nn0* new subtype. *Narrow triangle unequal margins.* (1) GPC-3. 1893–1912 cm, Sl.2, P25. (2) GPC-3, 1789–1811 cm, Sl.5, F39. (3) GPC-3, 1893–1912 cm, Sl.1, Q35. Type specimen. (4) GPC-3, 1789–1811 cm, Sl.6, L35. **5–12.** *a9/b1,5/c1/d1/e1/f4+(1,16)/g1/h0,5/i4/j4/k3,8/m0.50–0.75/n1.6–1.8/p2.2–2.8/q0,3,6/r0,4/s1,2/t1/z4/cc0/dd0/ee0/ff0/gg0/hh0/jj2/kk2/mm0/nn0* new subtype. *Triangle curved margin ends.* (5) DSDP 576-7-4, 69–75 cm, Sl.63-4, K13. (6) DSDP 577-11-4, 122–130 cm, Sl.63-1, Q40. (7) GPC-3, 1789–1811 cm, Sl.7, E30. (8) GPC-3, 1789–1811 cm, Sl.7, B23. (9) DSDP 577-11-4, 122–130 cm, Sl.63-1, F30. (10) DSDP 577-11-4, 122–130 cm, Sl.63-1, K20. (11) GPC-3, 1789–1811 cm, Sl.2, E32. Type specimen. (12) DSDP 576-7-4, 69–75 cm, Sl.63-1, S46.