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PALEOECOLOGICAL TRANSECT OF WESTERN PACIFIC OCEAN LATE PLIOCENE COCCOLITH FLORA: PART I.– TROPICAL ONTONG-JAVA PLATEAU AT ODP 806B

BY

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ABSTRACT

Preliminary quantitative analysis of coccolith floras from 102 Pliocene samples from Ontong-Java Plateau supports a long cooling trend from about 3.60 Ma to 2.40 Ma with minor oscillations near 41,000-year duration indicated in Core 806B-8 in Subzone CN12aC and CN12b based on the *Coccolithus/Calcidiscus* ratio (Co/Ca). Use of this ratio accentuates the paleoecologic contrast between cool-water *Coccolithus* and warm-water *Calcidiscus* for tropical sites. Among the species of *Discoaster*, the *D. brouweri/D. pentaradiatus* ratio also proved paleoecologically useful. The signal paleoecologic event in this study is the sudden arrival of *Coccolithus pelagicus* at about 2.76 Ma in Subzone CN12aC. Biostratigraphically, this study provides three new subdivisions (A, B, C) of the *Discoaster tamalis* Subzone (CN12a) based on the extinctions of *Sphenolithus* spp. and *Discoaster variabilis* at tropical sites in the Pacific and Atlantic Oceans.

INTRODUCTION

This report deals with the tropical midpoint of a three-point paleoecological transect of late Pliocene coccolith floras in the western Pacific Ocean. As a part of the U.S. Geological Survey Pliocene Global Climate Change Program for FY 1991, the coccolith study was originally approved by the program and project chiefs (R. Z. Poore and H. J. Dowsett) as a survey of 20 oceanic sites in the Pacific for paleo-ecological variation and trends in late Pliocene coccolith Subzone CN12a (*Discoaster tamalis* Subzone of Bukry, 1971 and 1973). This plan was replaced, through consultation with R. Z. Poore, by a detailed study of three sites in the western Pacific where long continuous cored sections could be sampled at about 10,000-year intervals to help recognize possible paleoecological responses at

23,000-, 41,000- and 100,000-year intervals of Milankovitch cycle variations (Ruddiman and McIntyre, 1981; Ruddiman and Raymo, 1988). Paleoecological indicator taxa that would occur at all three transect sites were selected for counting, such as *Calcidiscus, Coccolithus, Discoaster,* and *Helicosphaera.*

The main goal of this project is to quantify abundance variation of key coccolith taxa that could indicate paleoceanographic surface-water conditions during a late Pliocene period of global temperature decline around 3 Ma. Such variation could be indicative of paleoclimatic and Milankovitch cycles through use of close-spaced sampling in continuous ocean sections. The best core recovery in coccolith-rich continuous ocean sections was selected at DSDP 590A (latitude 31°S), ODP 782A (latitude 31°N), and at equatorial ODP 806B (latitude 0°). These three holes provide a 62° transect and high sedimentation rates (approximately 30 Bubnoffs), so a 10,000-year sample interval could be studied (Figure 1). Hopefully, the results reported here support further funding for study of the other sites.

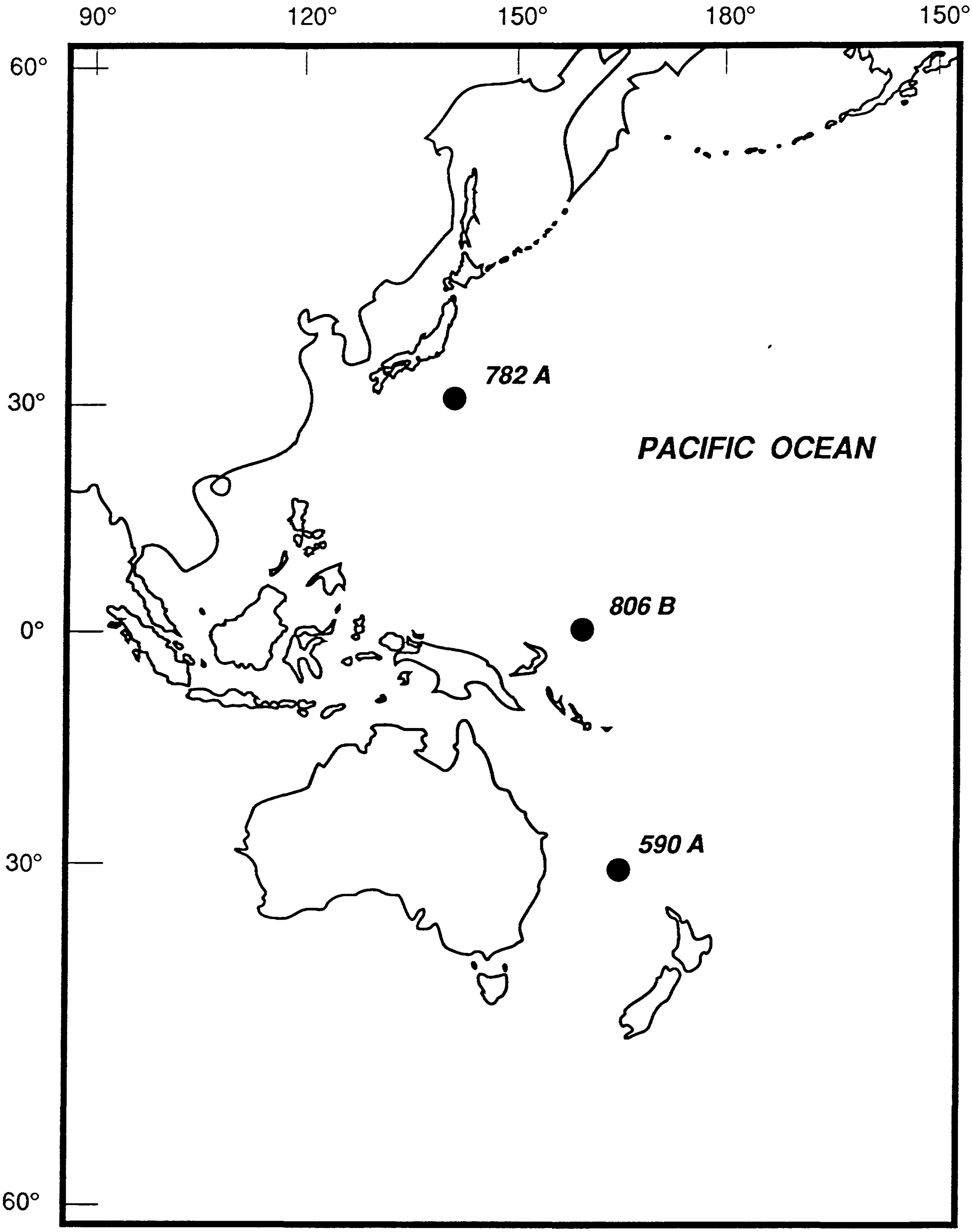

Figure 1. Location of western Pacific Ocean transect sites.

METHODS AND MATERIALS

A total of 102 samples from Ontong-Java Plateau Hole ODP 806B (latitude 0°19.11'N, longitude 159°21.69'E, water depth 2519.9 m) were prepared as coccolith smear slides for light microscope study (Bukry and Kennedy, 1969). Bright-field and cross-polarized light modes were used to count selected coccoliths in these samples. Because this is the preliminary part of the project, a survey of key coccoliths was done to determine what range of variation existed at an equatorial site. Therefore, all species of *Discoaster* were quantified quickly by counting the first hundred specimens for each sample at X800 magnification to provide numbers of warm- and cool-water taxa, such as *D. pentaradiatus* and *D. surculus* (Bukry, 1978, 1981). A separate count for other selected coccoliths of *Calcidiscus, Coccolithus, and Helicosphaera* was done at X600 magnification for the total census in ten fields of view (each field area is 0.1 mm^2) which yields the number of specimens in 1.0/mm^2 (Martini and Worsley, 1971; Gard and Crux, 1991). These standard counts through the section were used to calculate selected ratios to indicate paleoceanographic trends and fluctuations.

Since this study is a preliminary assessment of paleoecologic variation, the biostratigraphic resolution provided is based on only about 200 specimens of placoliths and discoasters for each sample. The zonation used is based on Okada and Bukry (1980), with further subdivision of subzone CN12a into three new subdivisions. The time scale for this study is from Backman and Shackleton (1983).

BIOSTRATIGRAPHY

The late Pliocene interval studied at ODP 806B (63.04 mbsf to 95.48 mbsf) is biostratigraphically zoned by coccoliths using a modification of the low-latitude Okada and Bukry (1980) system. Subzone CN12a at the base of the late Pliocene has been further subdivided by the use of additional extinction events for *Sphenolithus* spp. and *Discoaster variabilis.* Use of the *Sphenolithus* extinction following the *Reticulofenestra pseudoumbilica* extinction (Subzone CN11b, top) was suggested by Boudreaux (1974) in tropical floras and the *D. variabilis* extinction following *Sphenolithus* was suggested by Backman and Shackleton (1983) for the tropical Pacific. These events were applied successfully in a detailed biostratigraphic study of North Atlantic Ocean cores from DSDP 396, 546, 608, 611D, 659A, ODP 667A and 672A (Bukry, unpublished data, 1990; see Appendix I). The three new biostratigraphic units that subdivide Okada and Bukry (1980) Subzone CN12a are defined herein.

CN12aA. *Discoaster tamalis* (*Sphenolithus* spp.) Subzone

Definition: This unit is bounded by the extinction of *Reticulofenestra pseudoumbilica* below and the extinction of *Sphenolithus* spp. at the top. The assemblage is typical of the *Discoaster tamalis* Subzone (see Bukry, 1973a) but must include *Sphenolithus* spp.

Remark: CN12aA is not related to the earlier *Sphenolithus abies* Zone of Boudreaux and Hay (1969) which was defined with the *Discoaster surculus* extinction at the bottom and the *Sphenolithus abies* extinction at the top.

Occurrence: The type locality is ODP 806B from sample 11-1, 147-148 to 10-6, 14-15. Other occurrences are recorded at ODP 659A, ODP 667A, and ODP

672A, all at low-latitude (see Appendix I).

CN12aB. *Discoaster tamalis* (*Discoaster variabilis*) Subzone

Definition: This unit is bounded by the extinction of *Sphenolithus* spp. below and the extinction of *Discoaster variabilis* above. The assemblage is typical of the *D. tamalis* Subzone but must contain *D. variabilis* without *Sphenolithus* spp.

Occurrence: The type locality is ODP 806B from sample 10-5, 131-132 to 10-2, 47-48. Some sporadic occurrences above this level could extend the interval higher, if later proven to be in place. Other occurrences are at DSDP 546, ODP 659a, ODP 667A, and ODP 672A (see Appendix I).

CN12aC. *Discoaster tamalis* (NO *D. variabilis*) Subzone

Definition: This unit is bounded by the extinction of *Discoaster variabilis* below and the extinction of *D. tamalis* at the top. The assemblage is typical of the *D. tamalis* Subzone but lacks *Sphenolithus* and *D. variabilis*.

Occurrence: The type locality is ODP 806B from sample 10-2, 14-15 to 8-4, 80-81. Other occurrences are at DSDP 546, ODP 659A, ODP 667A, and ODP 672A.

The level of the last *Discoaster variabilis* to define the top of CN12aB at ODP 806B is based on the last consistent occurrence for the 100-specimen count. Minor, sporadic, higher occurrences could be from mixing or the result of the minimum count and a declining population. The latter is likely, because a comparison to the biostratigraphic study of nearby Ontong-Java Plateau DSDP Site 289 (Shafik, 1975) shows the late Pliocene arrival of *Coccolithus pelagicus* just below the disappearance of *Discoaster decorus*, and both below the disappearance of *D. variabilis* (as *D. pansus*). Although this matches the ODP 806B sequence for these taxa when the last and first sporadic occurrences are used, it does not match the last consistent occurrences which were used here (Table 1). A full biostratigraphic study which encompasses several hundred or several thousand discoasters will pinpoint and adjust these initial discoaster event levels.

Table 1. Occurrence of late Pliocene *Discoaster* and *Hayaster* species in ODP 806B Cores 7 to 11. Abundances are direct counts of the first hundred asterolith specimens. Species names are abbreviated: ASY = *Discoaster asymmetricus*, BLA = *D. blackstockae*, BRO = *D. brouweri*, CHA = *D. challengeri*, DEC = *D. decorus*, PEN = *D. penta-radiatus*, PER = *Hayaster perplexus*, SUR = *D. surculus*, TAM = *D. tamalis*, TRD = *D. tridenus*, TRR = *D. triradiatus*, VAR = *D. variabilis*, and Spp = *D.* spp.

Sample		ASY	BLA	BRO	CHA	DEC	PEN	PER	SUR	TAM	TRD	TRR	VAR	Spp
7-7,	4- 5			92			3	5				X		
	69- 70			99								1		
8-1,	32- 33	2		96			2							
	65- 66	1		97			1					1		
	98- 99			97			1					2		
	131-132			94			2	1	1			1		
8-2,	14- 15	2		91							3	4		
	47- 48			92			7	1						
	80- 81			92			3	1			4			
	113-114			97			1					2		
	147-148			85			15					X		
8-3,	32- 33	2		92			6	X						
	65- 66			83			16					1		
	98- 99	4		96								X		
	131-132			74			24	X	1?	X		1		

Sample		ASY	BLA	BRO	CHA	DEC	PEN	PER	SUR	TAM	TRD	TRR	VAR	Spp
8-4,	14- 15	2		94			3	X	1					
	47- 48	3		87			9					1		
	80- 81	2		82			6		1	8			1	
	113-114	4		85			7			2		2		
	147-148		1	80			12			1	1	2	3	
8-5,	32- 33	2		81			12		1?	3			1	
	65- 66	1		93			3					3		
	98- 99	1		81		1	16	X		X		1		
	131-132	3		85			10	X				2		
8-6,	14- 15	2		84	X		13			1		X		
	47- 48	2		93			3	1		X		1		
	80- 81	1		88			10	1						
	113-114	6		75			15	4				X		
	147-148	1		91			3	1		1		1	1	
8-7,	32- 33		1	63		1	28	1	3			2		1

Sample		ASY	BLA	BRO	CHA	DEC	PEN	PER	SUR	TAM	TRD	TRR	VAR	Spp
	61- 62	X		94			3	1		1		1	1	
9-1,	0- 1	3		86			9			2				
	32- 33	1		84			14					1		
	65- 66	1	1	85			10	2			1			
	98- 99	2		94			1			1		2		
	131-132	1		77			15	1	3	1				2
9-2,	14- 15	3		81			14	1						1
	47- 48	5		64			28			1				2
	80- 81	2		85			8			3				2
	113-114	2		76		1	15	3	1					2
	147-148	3		71			20	1	1					4
9-3,	32- 33	1		60			36			3				
	65- 66	1		45		3	42	5	1				1	2
	98- 99	2		25			70	2					1	
	131-132	3		48			43	2	2	1			1	

Sample		ASY	BLA	BRO	CHA	DEC	PEN	PER	SUR	TAM	TRD	TRR	VAR	Spp
9-4,	14- 15	7		80			8		2	1		X	2	
	47- 48	1	1	96			2					1		
	80- 81			81			15	1	3			X		
	113-114	3		95			1					X	1	
9-5,	0- 1	5		60			29	2	1	2			1	
	32- 33	2		89				1	4			1	3	
	65- 66	6	X	90		X	1	1	X			1	1	
	98- 99	3		93			1	1	2	X		X		
	131-132	1		91			7	1						
9-6,	14- 15	2		92			5	X				1		
	47- 48	1		97			1					1		
	80- 81	3	2	78			11	2		X		4		
	113-114	2	X	90			3	2	1	2		X		
	147-148	4		76			14		1	3		1	1	
9-7,	32- 33			91			5	3		1				

Sample		ASY	BLA	BRO	CHA	DEC	PEN	PER	SUR	TAM	TRD	TRR	VAR	Spp
	65- 66	8		78			10		1	3				
	CC	6		70			21		1	2				
10-1,	32- 33	3		85			7		1	1		2	1	
	65- 66	9		65			14	3	2	5			1	1
	98- 99	1		81			11	1	2			1	1	2
	131-132	3		89		1	7	X						
10-2,	14- 15	3		87			7	1				2	X	
	47- 48			68		11	1						20	
	80- 81		X	54	4	1	25	X				2	14	
	113-114			71		2	17	1		1		1	7	
	147-148		1	94			1	X	1			1	2	
10-3,	32- 33	1		55	1	1	21	X		5			10	1
	65- 66	5		61	1		15	11		3		3	1	
	98- 99	1		18		3	58	X		3			15	2
	131-132	29		31			25	1		9	1		4	

Sample		ASY	BLA	BRO	CHA	DEC	PEN	PER	SUR	TAM	TRD	TRR	VAR	Spp
10-4,	14- 15	16		55	2	2	7	X					18	
	47- 48	3		28		11	25	3					29	1
	80- 81	1		37	1	1	43	1		4		1	11	
	113-114	1		79			12	X	1				7	
	147-148	4		67	4	2	8		1			1	12	1
10-5,	32- 33	2		46	1		31		9	2		1	8	
	65- 66	2		32			6	X	10				49	1
	98- 99	2		54		1	21	1	11	1			8	1
	131-132			63		1	27		2				7	
10-6,	14- 15		X	47	1	1	18		1	1		1	27	3
	47- 48	2		66	2		5	1	3				18	3
	80- 81	6		54			17	3	3				12	5
	113-114	3		28	3		33	4		2	1	1	21	3
	147-148	7	2	12			58	14	2	1			3	1
10-7,	32- 33	5		53	2		19	5	5	2	1		5	7

Sample		ASY	BLA	BRO	CHA	DEC	PEN	PER	SUR	TAM	TRD	TRR	VAR	Spp
	61- 62	12		43			33	1	7	X		X	3	1
11-1,	14- 15	17		38			23		4	3		2	11	2
	47- 48	6		44			15	1	8	1			14	11
	80- 81	3		55		1	21	3	4				8	5
	113-114			68			19	1	1			1	8	2
	147-148	2		66			21		2	1		1	7	
11-2,	32- 33	5		56			25	1	7	1			5	
	65- 66	2		47	1		32		7				9	2
	98- 99	15		64			8	3	5	3			2	
	131-132	9		53	1		11	2	5				18	1
11-3,	14- 15	5		51			14	X	12	1			17	2
	47-48	3	2	78			6	8					3	

X = Noted outside 100 count during placolith study

On the basis of the preliminary biostratigraphic time scale (Figure 2), there appears to be an increase in sedimentation rate when *Coccolithus pelagicus* arrived (Core 9, 2.76 Ma). This could be a combined effect from increased productivity of cooler waters and possible increased bottom sediment winnowing and drifting on the plateau (Wu and Berger, 1991) as sea level began dropping. Bottom currents could sweep fine particles from high areas to lower depths on the plateau.

PALEOECOLOGIC ASSESSMENT

As a tropical shallow-water plateau site, ODP 806B could be expected to show only minor floral or paleotemperature variation in a predominantly tropical coccolith assemblage. Instead of large changes from warm-water discoasters to cool-water discoasters, to exclusion of discoasters by cold water, more subtle ratio changes between warm and temperate placoliths and discoasters would be expected at the tropical reference site. The real comparative interpretations should result from analyzing coeval assemblages between ODP 806B and the austral and boreal reference sites at latitude 31° (DSDP 590A and ODP 782A). In order to make an internal comparison at ODP 806B, alone, two different coccolith counts were made. The first, a discoaster count, is keyed on warm-water *D. pentaradiatus*, warm-temperate *D. brouweri* and temperate *D. variabilis* (Bukry, 1975, 1978, 1981). Among the larger, easily quantified, placoliths, the specimens of warm-water *Calcidiscus, Helicosphaera* and cold-water *Coccolithus* were counted as the guides to paleoecologic variation. *Calcidiscus* and *Helicosphaera* have a wide geographic range (McIntyre, 1967; Roth and Berger, 1975) but show increased abundances in warmer-water conditions (Geitzenauer, 1969; Gard, 1989; Gard and Crux, 1991). *Coccolithus pelagicus* provides the cold-water guide with a Holocene

Geologic Age	Subzonal Units	Age (Ma)	ODP 806B Sample (Depth mbsf)	Remarks
	CN12c			
	---------	2.41	8-3, 130 (67.80)	
	CN12b			
Late	---------	2.65	8-4, 80 (68.80)	
Pliocene	CN12aC			1. Local base of *Coccolithus pelagicus* at 75.63 m and 2.76 Ma.
	---------	2.90	10-2, 47 (84.47)	
	CN12aB			2. Local range of *Discoaster decorus* from 83.81 m to 89.81 m and 2.84 Ma to 3.41 Ma.
	---------	3.45	10-6, 14 (90.14)	
	CN12aA			
--		3.56	11-2, 32 (93.82)	
Early Pliocene	CN11b			

Figure 2. Preliminary coccolith biostratigraphy for Hole ODP 806B. Samples at top of subzones shown. Ages from Backman and Shackleton (1983).

and late Pleistocene temperature range of 2° to 15°C and with optimal temperatures of 8° to 12°C (McIntyre, 1967; Roth and Berger, 1975). The late Pliocene occurrences of *C. pelagicus*, described from the tropical Pacific Ocean at DSDP 62.1, 157, 158, 289, 419 to 421, 424, 425, 428, and 429 (Bukry, 1973b, 1980; Martini and Worsley, 1971; and Shafik, 1975), suggest a warmer-water race of *C. pelagicus* before the late Pleistocene (Bukry, 1981), or residence at the bottom of the photic zone where lower optimal temperatures would be located (Bukry, 1973b). Whatever the actual temperature range significance of late Pliocene tropical *C. pelagicus*, it is considered to represent a cooling phase, since according to Gard (1989) "*C. pelagicus* is a cold-water preferring species that cannot exist in sub-tropical or warmer waters" for the late Quaternary.

An examination of ratios between taxa counted shows that the best guides to paleoecologic trends are the *Coccolithus/Calcidiscus* ratio (Co/Ca) and the *Discoaster brouweri/D. pentaradiatus* ratio (B/P) (Table 2). Each ratio should increase with cooler conditions through the late Pliocene section and reflect short-term reversals. Gard (1989) pointed out the inverse relationship of *Coccolithus pelagicus* and *Calcidiscus leptoporus* abundance in the late Quaternary. Use of the genus level for this survey at ODP 806B combines barred and unbarred *C. pelagicus* of all sizes for *Coccolithus* and undifferentiated sizes of *C. leptoporus* and *C. macintyrei* for *Calcidiscus.*

Examination of the abundances of key species through the late Pliocene interval studied at ODP 806B (63.04 mbsf to 95.48 mbsf) shows support for the presumed cooling trend from Subzone CN11b to CN12c. The signal paleoecologic event is the arrival and quick flourishing of cold-water *Coccolithus pelagicus*

TABLE 2. Coccolith counts and ratios of abundance for the late Pliocene CN11b to CN12c samples from ODP 806B. Placolith data based on abundance per 1mm^2. Discoaster data based on count of first 100 specimens. Abbreviations: B = *Discoaster brouweri*, P = *D. pentaradiatus*, H = *Helicosphaera*, Ca = *Calcidiscus*, Co = *Coccolithus*.

Sample		Ratios				Coccolith Counts		
		B/P	H/Ca	Co/Ca	Co/H	Ca	Co	H
7-7,	4- 5	31	1.6	2.7	1.6	21	56	34
7-7,	69- 70	>99	1.9	0.9	0.5	17	16	32
8-1,	32- 33	48	2.5	3.1	1.3	20	62	49
	65- 66	97	2.5	2.6	1.1	8	21	20
	98- 99	97	2.2	3.0	1.4	17	51	37
	131-132	47	6.9	7.4	1.1	7	52	48
8-2,	14- 15	>91	1.3	1.7	1.3	19	32	25
	47- 48	13	0.8	0.8	1.0	44	33	33
	80- 81	24	0.8	0.8	1.1	31	26	24
	113-114	97	0.3	0.6	1.8	65	40	22
	147-148	5.7	0.9	0.5	0.9	30	16	27
8-3,	32- 33	15	2.6	2.0	0.8	20	39	52
	65- 66	5.2	1.3	1.0	0.8	15	15	20
	98- 99	>96	4.2	2.6	0.6	9	23	38
	131-132	3.1	2.9	2.9	1.0	12	35	35
8-4,	14- 15	31	1.2	4.7	4.0	17	80	20
	47- 48	9.7	1.6	4.1	2.5	8	33	13
	80- 81	14	1.7	3.1	1.8	30	92	52
	113-114	12	2.6	3.4	1.3	21	72	54
	147-148	6.7	2.1	5.1	2.5	14	72	29
8-5,	32- 33	6.8	2.1	2.3	1.1	20	45	42

		Ratios				Coccolith Counts		
Sample		B/P	H/Ca	Co/Ca	Co/H	Ca	Co	H
	65- 66	31	2.1	2.8	1.4	16	45	33
	98- 99	5.1	2.1	0.3	0.1	17	5	35
	131-132	8.5	3.2	3.0	0.9	18	54	58
8-6,	14- 15	6.5	10	18	1.7	6	106	61
	47- 48	31	1.7	5.4	3.2	15	82	26
	80- 81	8.8	3.0	12	3.9	11	128	33
	113-114	5.0	4.5	11	2.5	6	67	27
	147-148	30	9.3	36	3.9	3	109	28
8-7,	32- 33	2.3	2.4	1.4	0.6	32	46	76
	61- 62	13	2.1	2.6	1.2	27	69	58
9-1,	0- 1	9.6	3.7	17	4.5	7	118	26
	32- 33	6.0	3.0	1.3	0.4	23	30	68
	65- 66	8.5	0.9	0.1	0.1	68	5	61
	98- 99	94	0.7	0.1	0.1	44	3	31
	131-132	5.1	0.6	--	--	97	0	63
9-2,	14- 15	5.8	1.3	--	--	40	0	53
	47- 48	2.3	2.8	--	--	15	1	42
	80- 81	11	4.4	--	--	8	1?	35
	113-114	5.1	1.3	0.2	0.2	17	4	22
	147-148	3.6	6.0	--	--	6	0	36
9-3,	32- 33	1.7	3.8	--	--	18	0	68

		Ratios				Coccolith Counts		
Sample		B/P	H/Ca	Co/Ca	Co/H	Ca	Co	H
	65- 66	1.1	0.9	--	--	66	0	57
	98- 99	0.4	0.3	--	--	94	0	31
	131-132	1.1	0.4	--	--	98	0	35
9-4,	14- 15	10	0.9	--	--	35	0	33
	47- 48	48	0.1	--	--	58	0	6
	80- 81	5.4	0.3	--	--	22	0	6
	113-114	95	0.4	--	--	32	0	12
9-5,	0- 1	2.1	0.9	--	--	32	0	28
	32- 33	>89	0.2	--	--	64	0	11
	65- 66	90	0.3	--	--	42	0	14
	98- 99	93	1.5	--	--	26	0	40
	131-132	13	0.7	--	--	54	0	36
9-6,	14- 15	18	0.7	--	--	31	0	22
	47- 48	97	0.5	--	--	34	0	17
	80- 81	7.1	0.5	--	--	71	0	36
	113-114	30	0.6	--	--	44	1	27
	147-148	5.4	0.9	--	--	34	0	32
9-7,	32- 33	18	1.0	--	--	51	0	51
	65- 66	7.8	1.1	--	--	15	0	16
	CC	3.3	1.2	--	--	12	0	14
10-1,	32- 33	12	1.0	--	--	32	1	32

		Ratios				Coccolith Counts		
Sample		B/P	H/Ca	Co/Ca	Co/H	Ca	Co	H
	65- 66	4.6	0.6	--	--	32	0	18
	98- 99	7.4	1.1	--	--	41	0	45
	131-132	13	0.6	--	--	47	0	30
10-2,	14- 15	12	1.1	--	--	35	0	37
	47- 48	68	0.6	--	--	60	0	34
	80- 81	2.2	0.8	--	--	52	0	39
	113-114	4.2	0.4	--	--	65	1	27
	147-148	94	1.6	--	--	36	0	56
10-3,	32- 33	2.6	0.9	--	--	50	0	43
	65- 66	4.1	0.9	--	--	50	0	44
	98- 99	0.3	1.1	--	--	31	0	34
	131-132	1.2	1.3	--	--	40	0	51
10-4,	14- 15	7.9	0.4	--	--	68	0	25
	47- 48	1.1	1.2	--	--	19	0	23
	80- 81	0.9	0.8	--	--	64	0	48
	113-114	6.6	0.3	--	--	49	0	14
	147-148	8.4	0.9	--	--	59	0	51
10-5,	32- 33	1.5	0.5	--	--	68	0	34
	65- 66	5.3	0.5	--	--	68	0	37
	98- 99	2.6	0.4	--	--	76	0	29
	131-132	2.3	0.4	--	--	46	0	20

Sample		Ratios				Coccolith Counts		
		B/P	H/Ca	Co/Ca	Co/H	Ca	Co	H
10-6,	14- 15	2.7	1.1	--	--	49	1	53
	47- 48	13	0.7	--	--	73	0	49
	80- 81	3.2	1.1	--	--	33	0	35
	113-114	0.8	1.4	--	--	37	0	52
	147-148	0.2	1.1	--	--	22	0	24
10-7,	32- 33	2.8	0.7	--	--	47	0	33
	61- 62	1.3	0.9	--	--	50	0	47
11-1,	14- 15	1.7	1.1	--	--	35	0	37
	47- 48	2.9	1.3	--	--	25	0	32
	80- 81	2.6	0.6	--	--	41	0	23
	113-114	3.6	0.1	--	--	81	0	12
	147-148	3.1	1.2	--	--	37	0	44
11-2,	32- 33	2.2	0.8	--	--	29	0	24
	65- 66	1.5	1.0	--	--	33	0	33
	98- 99	8.0	0.8	--	--	26	0	22
	131-132	4.8	2.0	--	--	20	0	39
11-3,	14- 15	3.6	2.5	--	--	26	0	65
	47- 48	13	1.8	--	--	27	0	49

between samples 9-2, 113-114 and 9-1, 0-1. Aside from single contaminated, reworked, or isolated specimens in 9-6, 113-114; 10-1, 32-33; 10-2, 113-114; and 10-6, 14-15, *C. pelagicus* is absent below 9-2, 113-114. It is consistently present in every sample above 9-1, 0-1, and commonly outnumbers *Calcidiscus*. The counts show a notable reduction in the numbers of *Calcidiscus* once *C. pelagicus* arrived, but *Helicosphaera* maintained the same numbers. The Co/Ca ratio can be calculated between 9-2, 113-114 and the top of the studied section at 7-7, 4-5. For the longer underlying section the Co/Ca ratio cannot be used, so to accommodate the whole section for this tropical reference a *Helicosphaera/Calcidiscus* ratio (H/Ca) was used with the *D. brouweri/D. pentaradiatus* ratio (B/P).

For Core 8, the Co/Ca ratio in core-section 8-6 has the highest (coldest) values of 5.4 to 36.9, with sections 8-4 and 8-1 the next highest--3.1 to 5.1 and 3.1 to 6.9. The intervening Core 8 sections have lower (warmer) ratios. For example, 8-5 is 0.3 to 3.0, 8-3 is 1.0 to 2.9, and 8-2 is 0.5 to 1.7. The distribution of these ratios suggests two warm and three cool oscillations in Core 8 or about one per section (through the whole 800,000-year study interval the 102 regularly spaced samples give an average 8,000 years increment; each core section about 40,000 years).

The other two ratios between less contrasting taxa, nevertheless, do show the trend to declining paleotemperatures through the section. This is especially easy to see when comparing the average ratio value for the whole section counted to the limited range average for the uppermost samples (coolest) to the lowermost samples (warmest). These values (Table 3) for the H/Ca ratio are 0.99 (average), 1.56 (upper) and 0.97 (lower); for the B/P ratio these values are 5.06 (average),

Table 3. Coccolith paleoclimatic indicator ratios averaged over selected stratigraphic intervals at ODP 806B. Deviation from average in parentheses.

Core-Section Interval	H/Ca	B/P
7-7 to 8-4	1.56 (+ 0.57)	15.2 (+10.14)
8-5 to 9-2	1.84 (+ 0.85)	6.80 (+ 1.74)
9-3 to 9-7	0.64 (- 0.35)	4.99 (- 0.07)
10-1 to 10-5	0.71 (- 0.28)	3.39 (- 1.67)
10-6 to 11-3	0.97 (- 0.02)	2.44 (- 2.62)
7-7 to 11-3	0.99 Average	5.06 Average

15.2 (upper) and 2.44 (lower). Because the section covers the timespan from about 3.60 to 2.40 Ma, just prior to the extinction of *D. pentaradiatus* at 2.35 Ma, the apparent success of the B/P ratio may be complicated by extinction parameters other than temperature. But the gradual disappearance of this warm-water discoaster through the whole section supports the global trend. The effects from moderate-sized glacial icesheets began at about 2.40 Ma (Ruddiman and Raymo, 1988).

CONCLUSION

Quantitative coccolith study for equatorial Hole ODP 806B shows that the signal paleoecologic event, the arrival of cold-water *Coccolithus pelagicus,* occurred in upper part of the *Discoaster tamalis* Subzone (CN12aC) at about 2.76 Ma. *C. pelagicus* immediately began to outnumber *Calcidiscus* which suggests a significant regional cooling trend. Oscillations in the Co/Ca ratio in Core 8 should be useful in local ecostratigraphic analysis. Both the Co/Ca and B/P ratios are useful in CN12a for paleoecologic variation. Comparison to mid-latitude sites should reveal other useful paleoecologic relations for specifying global climate change in the western Pacific Ocean.

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LOCATION OF OCEAN CORING SITES

Site	Latitude	Longitude	Water Depth (m)
DSDP			
62.1	1°52.2'N	141°56.0'E	2591
157	1°45.70'S	85°54.17'W	1591
158	6°37.36'N	85°14.16'W	1953
289	0°29.92'S	158°30.69'E	2206
396	22°58.88'N	43°30.95'W	4450
419	8°55.96'N	105°41.17'W	3274
420	9°00.10'N	106°06.77'W	3381
421	9°01.41'N	106°03.68'W	3339
424	0°35.33'N	86°07.81'W	2685
425	1°23.68'N	86°04.22'W	2850
428	9°02.77'N	105°26.14'W	3295
429	9°02.01'N	106°46.35'W	3406
546	33°46.71'N	9°33.86'N	3958
590A	31°10.02'S	163°21.51'E	1299
608	42°50.21'N	23°05.25'W	3526
611D	52°50.47'N	30°18.58'W	3195
ODP			
659A	18°04.63'N	21°01.57'W	3070
667A	4°34.15'N	21°54.68'W	3536
672A	15°32.40'N	58°38.46'W	4975
782A	30°51.66'N	141°18.85'E	2959

Site	Latitude	Longitude	Water Depth (m)
ODP			
806B	0°19.11'N	159°21.69'E	2520

COCCOLITH SPECIES CITED

Calcidiscus leptoporus (Murray and Blackman)

C. macintyrei (Bukry and Bramlette)

Coccolithus pelagicus (Wallich)

Discoaster asymmetricus Gartner

D. blackstockae Bukry

D. brouweri Tan

D. challengeri Bramlette and Riedel

D. decorus (Bukry)

D. pansus (Bukry and Percival)

D. pentaradiatus Tan

D. surculus Martini and Bramlette

D. tamalis Kamptner

D. tridenus Kamptner, emended Bukry

D. triradiatus Tan

D. variabilis Martini and Bramlette

Hayaster perplexus (Bramlette and Riedel)

Reticulofenestra pseudoumbilica (Gartner)

Sphenolithus abies Deflandre

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Appendix I. Correlation of North Atlantic JOIDES site sample sequences by nannofossil subzonal bioevent boundaries.

CN UNIT / JOIDES SITE	396	546	608	611D	659A	667A	672A
12d	-	?7-3 (90-92) 7-4 (90-92 8-4 (32-34)	-	-	8-3 (80-82)	5-1 (20-21) 5-4 (118-120)	-
12c	-	Poor Undiff. 8-4 (90-92)	-	-	8-6 (70-72)	5-5 (45-47)	-
12b	8-6 (70-72)	8-5 (25-27)	-	3-6 (100-102) 4-7 (10-12)	9-3 (50-52) 9-5 (10-12)	6-1 (50-52)	7-2 (22-24)
12aC	8-6 (125-127)	8-6 (32-34) 9-5 (30-32)	10-6 (60-62) All	5-1 (40-42) All	10-1 (50-52) 10-3 (65-67)	6-1 (102-104) 6-2 (145-147)	7-4 (100-102) 8-1 (100-102)
12aB	Mixed: CN10,11,12	9-5 (90-92) 10-3 (75-77)	Undiff. (No *D.vari*) (No *Sph.*)	Undiff. (No *D. vari*) (No *Sph.*)	10-3 (95-97) 11-6 (20-22)	6-3 (30-32) 6-6 (70-72)	8-3 (100-102) 9-6 (100-102)
12aA	9-5 (78-80) to 10-6 (70-72)	-	12-3 (80-82)	7-5 (50-52)	12-1 (60-62)	6-6 (98-100) 7-1 (130-132)	9-7 (20-22) 10-4 (50-52)

CN UNIT \ JOIDES SITE	396	546	608	611D	659A	667A	672A
11b		10-4 (75-77) 10-5 (75-77)	-	-	13-1 (100-102) 14-1 (100-102)	7-4 (22-24)	-
11a		-	-	-	Undiff.	-	-