REVISED ZONAL SUBDIVISION OF THE LATE MIOCENE NANNOPLANKTON BIOSTRATIGRAPHY FOR KUTEI BASIN

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ABSTRACT

Lithological complexity and intense hydrocarbon exploration with the objective of Late Miocene sediments in Kutei Basin has provided the impetus for more refined Late Miocene nannoplankton zonation than the standard global schemes of Martini (1971). Investigation to the quantitative nannoplankton analysis results in Kutei Basin has been done, and there is evident that the deltaic sediments of this basin give an excellent nannoplankton assemblage dataset to refine the Late Miocene biostratigraphy.

Biostratigraphically, Late Miocene ranges from the middle part of zone NN9 to the middle part of zone NN12 of Martini zonation (1971). Zone NN11 is the most crucial zone to be refined since this zone has long time interval (more than 2m.a.). In this paper, this zone can be subdivided into 7 subzones (NN11a-NN11g) based on relatively permanent occurrences of 6 biomarkers. They are from the base to the top, as follow: FO Discoaster quinqueramus, LO. Minilitha convalis, LO Discoaster bergenii, FO Amaurolithus primus, FO Reticulofenestra rotaria, LO, Discoaster berggrenii, LO. Reticulofenestra rotaria and LO Discoaster quinqueramus.

In spite of zone NN9, NN10 and NN12 which have relatively short stratigraphic ranges, each zone can also be subdivided into 2 subzones. The base and the top of zone NN9 is indicated respectively by the FO and LO Discoaster hamatus. It can be subdivided by the FO Discoaster prepentaradiatus into subzone NN9a and NN9b. Zone NN10 is marked by the LO Discoaster hamatus at the base and FO Discoaster quinqueramus at the top. It can be subdivided into subzones NN10a and NN10b by the LO Discoaster bollii. Zone NN12 is characterized by the LO Discoaster quinqueramus at the base and the FO Ceratolithus rugosus at the top. This zone can be subdivided into subzone NN12a and NN12b by the LO Helicosphaera intermedia.
Key words: biostratigraphy, nannoplankton, miocene, kutei basin

I. INTRODUCTION

The Kutei Basin represents one of the most economically important sedimentary basin in Indonesia (Figure 1). This basin is the largest and the deepest Tertiary basin in western Indonesia and covers an area of approximately 60.000 km^2 and contains a Tertiary sedimentary section of up to 14 km (Allen, 1998). Lithological complexity of deltaic sedimentation and intense hydrocarbon exploration with the objective of Late Miocene sediment in Kutei Basin has provided the impetus for more refined and precise Late Miocene nannoplankton zonation than those provided by the standard global schemes of Martini (1971) or Okada & Bukry (1980). Investigation to the quantitative nannoplankton analysis results in Kutei Basin has been done, and there is evident that the sediments of this basin give the excellent nannoplankton assemblage dataset to refine the Late Miocene nannoplankton biostratigraphy.

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Biostratigraphically, Late Miocene ranges from the middle part of zone NN9 to the middle part of zone NN12 of Martini zonation (1971). This age was a time of rapid evolution of Genera *Discoaster,* and there is an evident that some 17 species occur and some 20 species extinct during about 6.2 m.y of the Late Miocene time interval. Some species from Genera *Minilitha*, *Amaurolithus*, *Ceratolithus* and *Reticulofenestra* also evolved within this age. Based on the data above, the subdivision of Late Miocene must be better than 4 zones suggested by Martini (1971) or 4 zones and 6 subzones by Okada & Bukry (1980). The problem is to find their consistent stratigraphic events. Moreover, the studies in Indonesia have revealed that the stratigraphic ranges of several species are different from those in any publication, owing to paleolatitude, local environmental condition and litological factors. Even, some species are not recovered.

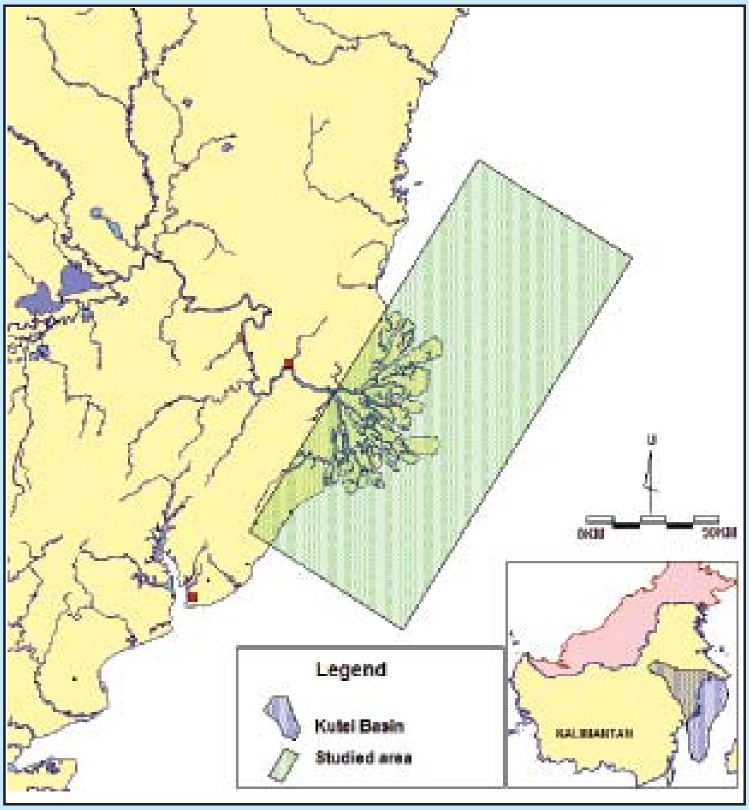

Figure 1
Kutei basin and studied area

II. MATERIAL AND METHODS

The basis of the Late Miocene nannoplankton biostratigraphic revision is results of nannoplankton biostratigraby from 23 well sections (5 well sections are displayed in the appendices). The samples comprises a great number of ditch cutting, core and SWC (side wall core), those were processed mainly using *smearing method* and embedded in Entellan. The analyzed interval was determined systematically and the observation was undertaken at a magnification of 1000x using light microscope (LM) in quantitative method. Observation techniques comprise *bright field*

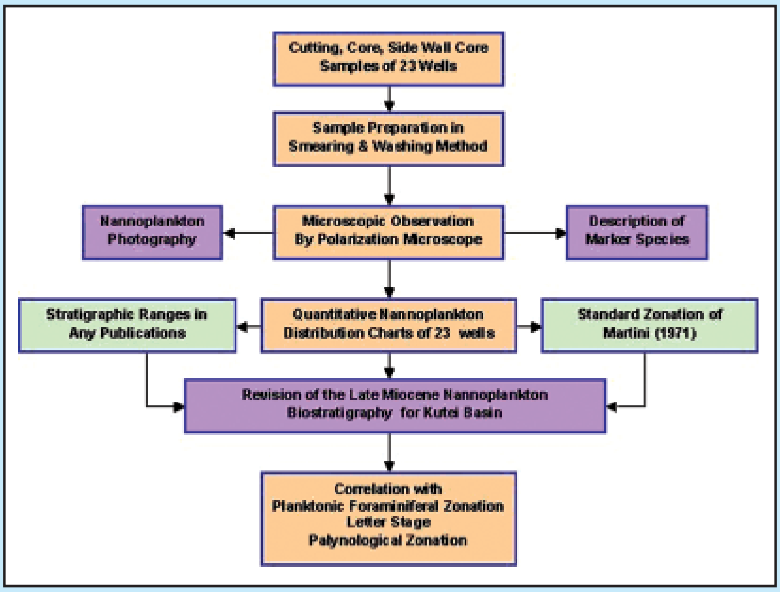

Figure 2
Flow chart of research methodology

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(BF), cross polarized light (XPL), Gypsum plate in XPL and *phase contrast.* Taxonomy and terminology in the description of index species refers to Perch-Nielsen (1985). The standard zonation of Martini (1971) is used as a mainframe to subdivide Late Miocene into several subzones, and then the result is correlated with planktonic foraminiferal zonation, Letter Stage and palynological zonation. (Figure 2).

III. LITHOSTRATIGRAPHY

Lithostratigraphy for Kutei Basin is in confusion since each petroleum companies use the different stratigraphic nomenclature. This paper refers to below stratigraphic column. This studied sections comprises of two lithostratigraphic units, include Balikpapan and Kampung Baru Groups. These units were deposited during the stratigraphic phase was contemporaneous with basin uplift and inversion, with the results a vast series of alluvial to deltaic and marine sediments. Balikpapan Group is composed by alternation of slightly calcareous to calcareous sandstones and shale with intercalation limestones. Kampung Baru Group is formed by sandstones with intercalation shale and coal.

IV. BIOSTRATIGRAPHIC REMARKS

The nannoplankton assemblages are recovered vary from rare to abundance and from low to high diversity in studied area. Their preservation is moderate to good. Biomarkers of Late Miocene are usually common and easily accomplished, although they are tend to be rare or absent in few well sections. Surprisingly, several bioevents of some species were recovered relatively consistent in the Late Miocene sediment succession after careful study. This phenomenon is possible to be utilized as local biomarkers to obtain the demand about higher resolution biostratigraphy, and furthermore it will be a reliable tool to make detail sedimentary correlation within Kutei Basin.

V. CONTROVERSY OF THE MIDDLE/ LATE MIOCENE BOUNDARY

The Middle/Late Miocene boundary in zonation of Martini (1971) is placed within NN9 by some authors and in the uppermost part of NN7 by other authors. This Paper refers to previously mentioned that is proposed by Martini (1971) and followed by Perch-Nielsen (1971). This event is represented by the the first occurrence (FO) of *Discoaster prepentaradiatus* which is correlative to the top of planktonic foraminiferal zone N14. Bown (1999) is one of the author that place the Middle/Late Miocene boundary in the uppermost part of NN7 that indicated by the extinction of broad and short arm *Discoaster* group (*Discoaster deflandrei* and *Discoaster kugleri).* The reason of extinction is uncertain, but it might be an asteroid impact that occurred at 11 Ma. Its crater name is Ewing (diameter 55km-150km) and placed in Western Pacific (oceanic crater). Such impact could result in severe global climate disruption (Paine, 2007). The abruptly change of climate

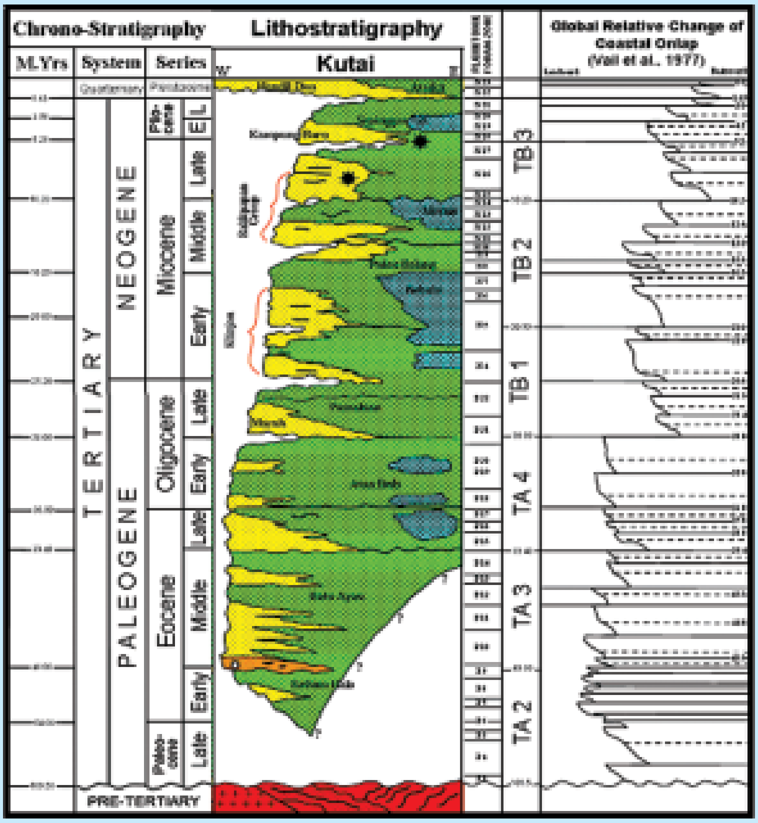

Figure 3
Kutei basin stratigraphic column

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from warmer in the top of Middle Miocene to colder in the base of Late Miocene is possibly indicated by the significant global sea level fall between Middle/ Late Miocene boundary (Haq et al., 1988).

VI. THE LATE MIOCENE/PLIOCENE BOUNDARY

Most of the authors agree that this boundary is placed within zone NN12 (correlative to the top of planktonic foraminiferal zone N17), which is coincide with the extinction of *Helicosphaera intermedia*. This species is the last isolated bridge form of Genera *Helicosphaera*. This event is corresponding to the climatic change from warmer to colder and the meteorite impact that occurred at about 5 Ma. The evident of meteorite impact is a crater named Kara-Kul (diameter 52 km) that placed in Tajikistan.

VIII. BIOSTRATIGRAPHIC REVISION

The standard zonation of Martini (1971) is used widely for hydrocarbon exploration in Kutai Basin, and even in all over the world. This fact is being main consideration to make this zonation to be a mainframe for subdivision of the Late Miocene zonation into several subzones to obtain a high resolution biostratigraphic scheme.

Based on the nannoplankton assemblages dataset, the Late Miocene that ranges from zone NN9 to zone NN12 can be subdivided as follows (Figure 4, Table 1-5):

Zone NN9

The bottom and the top of this zone are indicated respectively by the first occurrence (FO) and last occurrences (LO) *of Discoaster hamatus*. This zone can be subdivided into subzones NN9a and NN9b. Subzone NN9a is characterized by the FO of *Discoaster hamatus* at the bottom and the FO of *Discoaster prepentaradiatus* at the top. Subzone NN9b is marked by the FO of *Discoaster prepentaradiatus* at the bottom and the LO of *Discoaster hamatus* at the top. The boundary of subzone NN9a/NN9b is assumed representing the bottom of Late Miocene age.

Zone NN10

The bottom of this zone is assigned by the LO of *Discoaster hamatus*, whilst its top is indicated by the FO of *Discoaster quinqueramus*. Zone NN10 can be subdivided into subzones NN10a and NN10b. **S**ubzone NN10a is indicated by the LO of Discoaster hamatus at the bottom and the LO of Discoaster bollii at the top. Subzone NN10b is characterized by the LO of *Discoaster bollii* at the bottom and the FO of *Discoaster quinqueramus* at the top.

Zone NN11

The bottom and the top of this zone is marked respectively by the FO and LO of *Discoaster quinqueramus*. This zone can be subdivided from the base to the top into 7 subzones as follows: Subzone

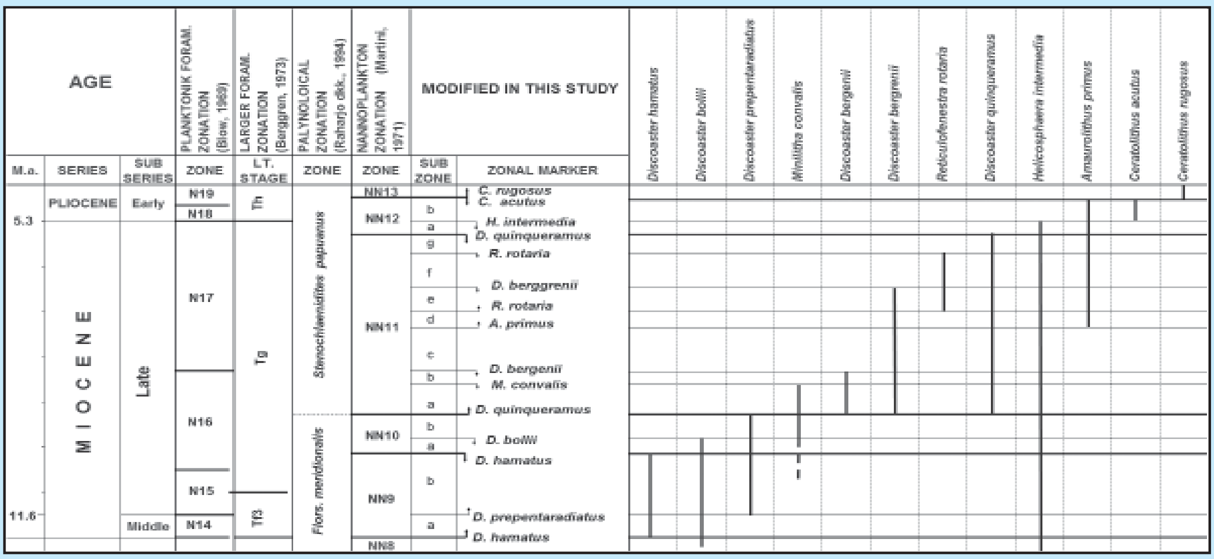

Figure 4.
Revision of the Late Miocene Nannoplankton Biostratigraphy, Stratigraphic Ranges of Index Species and Its Correlation with Planktonic Foraminiferal Zonation, Letter Stages and Palynological Zonation

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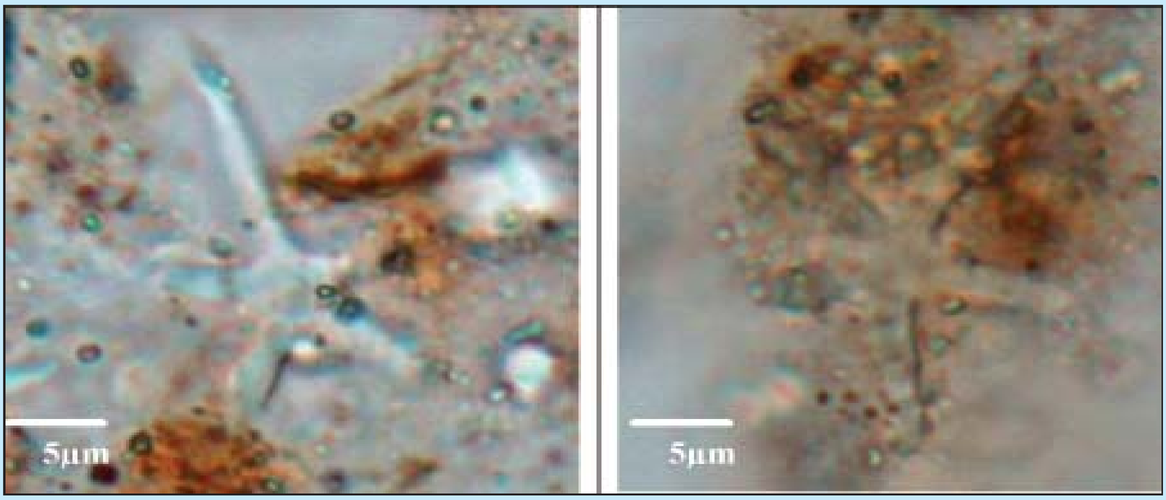
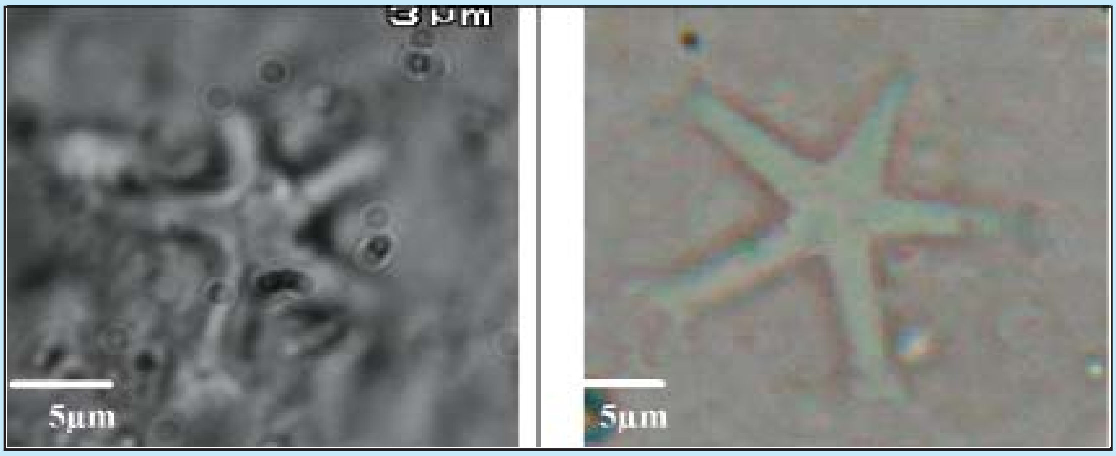
Plate 1

Discoaster hamatus **Martini and Bramlette, 1963**



Asterolith has 5 rays and non-birefringent. The rays are long, slender, somewhat curved, possess ridges in proximal surface, and turn sharply clockwise (in distal view) and downward near the end. The tip of rays is asymmetrical bifurcation, although the smaller branch appears to be a continuation of the main part of the arm as it extends in same direction. The other one is longer and lying in the different plane. Central area has a stellate knob in the proximal side, whilst the distal face is ornamented with depression around a small knob. The dimension ranges from 17µ to 23 µ. This species occurs only in zone NN9.

Discoaster prepentaradiatus **Bukry and Percival, 1971.**



Asterolith has 5 symmetrical arrangement rays and non-birefringent. The rays are relatively short and bifurcating at the tips in the same plane. The angle of bifurcation is about 120^{o} and symmetric. Central area is small and has a small knob. D. prepentaradiatus differs from the younger D. pentaradiatus by lack of the typical downward bent arms and the birefriengence of its asterolith. The dimension ranges from 13µ to 18µ. This species occurs in zone NN9 to NN10.

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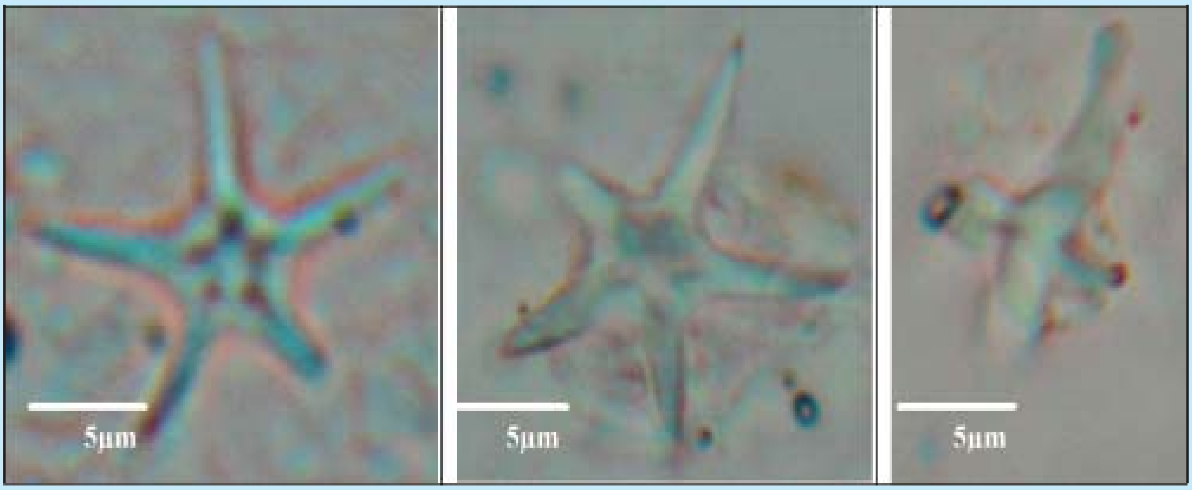
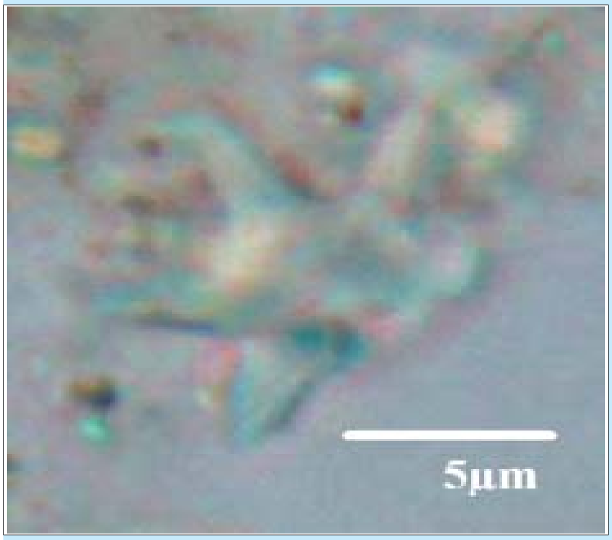
Plate 2

***Discoaster quinqueramus* Gartner, 1969c.**



Asterolith has 5 symmetrical tapering rays. Rays are long, slender and curve proximally. The tips of the rays are pointed. Rays has concavo-convex shape and non-bifurcation. Inter-ray area is V shape. Central area has large and high stellate proximal knob. In distal side, the central area exhibits characteristic ridges along the sutural lines. Depression occurs between the sutural ridges. Length of the rays is 2x to 3x of central area diameter. The dimension ranges from 10µ to 20µ. The occurrence of this species is only in zone NN11.

***Discoaster bollii* Martini & Bramlette, 1963**



Asterolith has 6 rays and wide central area. Rays are short, tapering and terminate into short and slender bifurcation. The angle of bifurcation is less than 90° and slightly asymmetry. The distal side of the central area is ornamented by a high stellate knob and depressions, whilst the proximal side has a lower and rounded knob, and the ridges radiating from knob towards the rays. The dimension ranges from 7µ to 12µ. This species occurs from zone NN8 to the middle part of zone NN10, but according to Bown (1999), this species is only recovered in zone NN8 to zone NN9.

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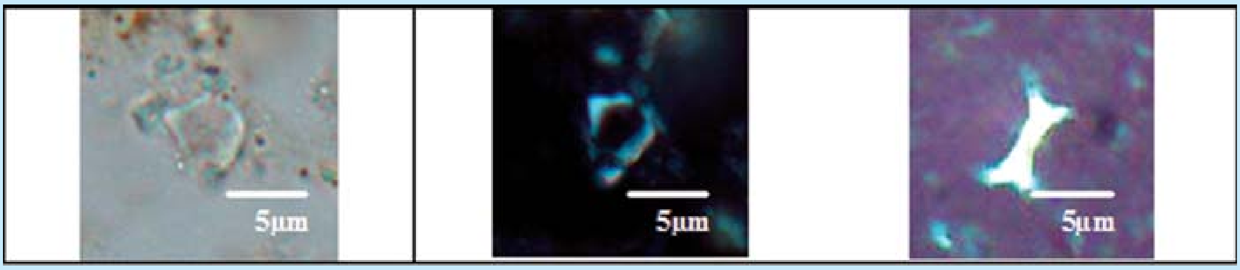
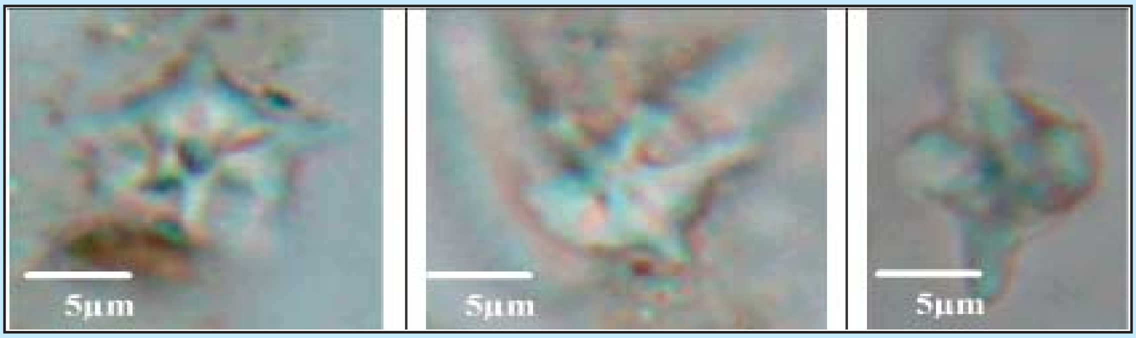
Plate 3

Minylitha convalis **Bukry, 1973b**



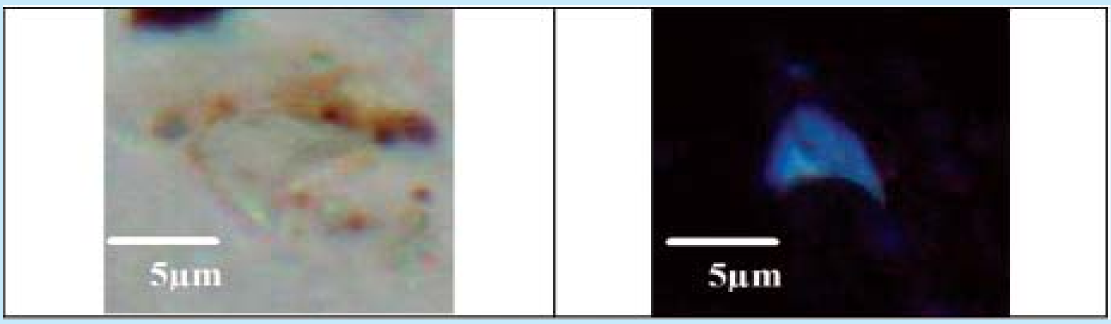
Nannolith consists of two polygonal convexo-concave calcite elements. The two elements are attached to each other by their convex surfaces. It has elevated rim and central area depression. Nannolith appears moderate bright around rim and dark in the center within polarized light. The strong birefringent is observed in lateral view which is roughly resemble of the letter between I or X. The dimension ranges from 4µ to 6µ. This species is found in the upper part of zone NN9 to the lower part of zone NN11, but very rare in zone NN9.

Discoaster bergenii **Knuttel et al., 1989**



This species appears like *Discoaster quinqueramus,* but central-area with knob is much wider and length of rays is much shorter (diameter of central area is more than 2x of free ray length). Inter-ray area forms U shape. The dimension ranges from 11µ to 16µ. Stratigraphic range is only in the lower part of NN11 (subzone NN11a-b).

Amaurolithus primus **(Bukry & Percifal, 1971) Gartner & Bukry, 1975**



Horseshoe shape ceratolith with asymmetric short horns, broad arch and slight keels. This ceratolith has roughly surfaces and shows weak birefringence between crossed nicols. This species is relatively small size, the dimension ranges from 4µ to 8µ. This species is found in the middle part of zone NN11 to zone NN12.

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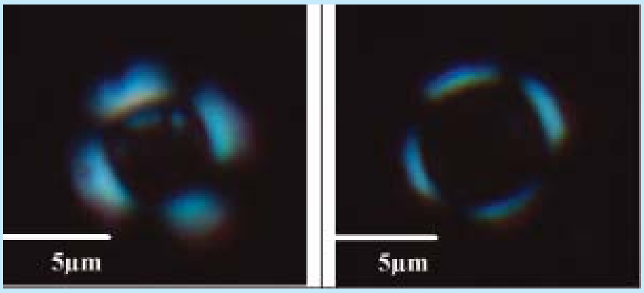
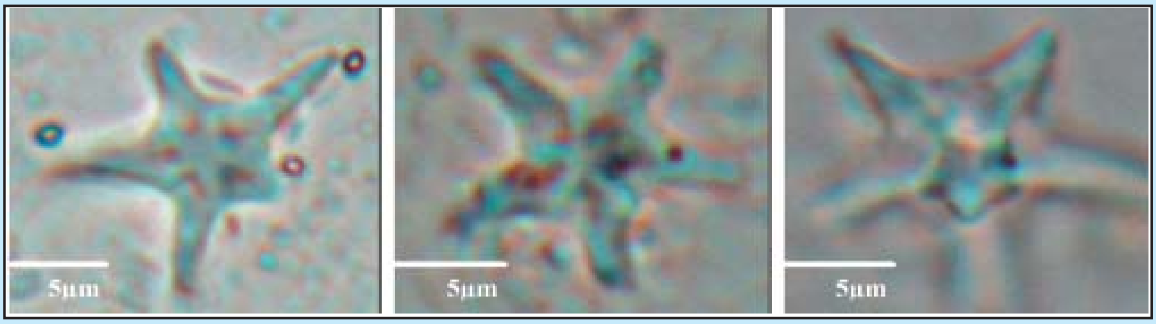
Plate 4

***Reticulofenestra rotaria* Theodoridis, 1984**



Placolith with circular outline and wide rounded central opening. Both proximal and distal shield shows strong birefringence between crossed nicols. This species is never abundant but distinctive. The diameter of outline ranges from 6µ to 9µ, whilst central opening from 5 to 7µm. The occurrence of this species is only in the upper part of zone NN11 (subzone NN11e-f).

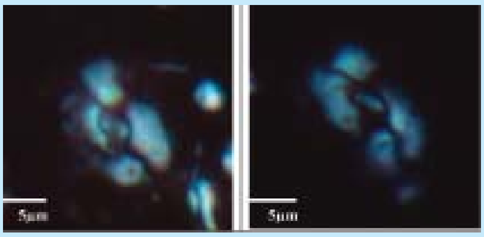
Discoaster berggrenii Bukry, 1971b.



The asterolith of this species is also like *Discoaster quinqueramus.* The Central-area of this species is wider than *Discoaster quinqueramus* but narrower than *Discoaster bergenii.* Central area diameter of this species is 1-2x of free ray length. The prominent stellate knob is present in the center of central area. Inter-ray area is relatively V shape. The dimension ranges from 11µ to 17µ. This species occurs in the lower part to the upper part of zone NN11 (subzone NN11a-e).

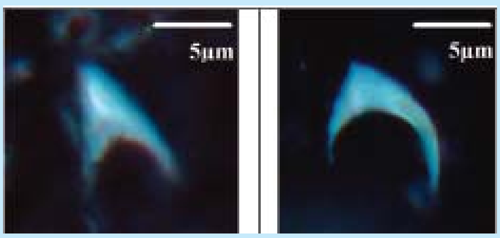
Plate 5

***Helicosphaera intermedia* Martini , 1965**



The helicolith of this species is symmetrically elliptical with a protruding terminal flange. Central opening is divided by an isolated sigmoid bridge that forms a steeper angle with major axis (<30°) with the result two slits are present beside the bridge. The dimension ranges from 9µ to 15µ. This species is found in the lower part of zone NP19 to middle part of zone NN12 (NP19 - subzone NN12a).

***Ceratolithus acutus* Martini , 1965**



The Ceratolith of this species has slightly asymmetrical horns and relatively broad arch with short apical spine. One horn is longer than the other. This species is often considered as the same taxon with *Ceratolithus armatus* (right picture) by some authors. The later form has a wider interior curvature and more asymmetrical horns. The dimension ranges from 4µ to 6µ. The occurrence of this species is only in the upper part of zone NN12.

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Age	Nannoplankton Zone	Subzone	Zonal Marker		Depth of Selected Samples (feet) "Well A"	Selected Species: Dictyococcites perlaevis	Helicosphaera carteri	Reticulofenestra pseudoumbilicus	Sphenolithus abies	Discoaster pentaradiatus	Ceratolithus rugosus	Ceratolithus acutus	Helicosphaera intermedia	Discoaster quinqueramus	Reticulofenestra rotaria	Discoaster berggrenii (long arm)	Amaurolithus primus	Discoaster berggrenii	Minylitha convallis	Discoaster bellus	Discoaster hamatus	Discoaster prepentaradiatus	Catinaster coalitus	Preservation: Etching	Overgrowth	Abundance
					10740	17	5	104	2	21	1													E2	O1	150
Early Pliocene	NN13				10770	16	5	32	2	13	1													E2	O1	72
			FO	C. rugosus	10800	12	2	105	1	41	2													E2	O1	164
			LO	C. acutus	10830	20	2	65	2	29		1												E2	O1	120
		b			11040	13	15	165	2	67		2												E2	O1	272
					11310	1	2	7	2	1		1												E2	O1	13
			LO	H. intermedia	11340	21		17	5	22			1											E2	O1	64
	NN12				11370	55	6	64	15	35			3											E2	O1	176
		a			11910	90	15	192	77	33			1											E2	O1	409
					11940	52	52	94	22	31			2											E2	O2	253
			LO	D. quinqueramus	12450	55	10	250	240	10				2										E2	O1	597
					12480	130	3	27	30	8				1										E2	O1	199
		g			12510	90	12	288	220	6				3			2							E2	O1	649
					12540	4	5	82	193	9				1										E1	O1	297
					12570	90	4	90	110	36				3										E2	O1	333
			LO	R. rotaria	12600	16	30	960	650	34				35	1		1							E2	O1	1733
		f			12630	33	6	90	450	9				50	3		1							E2	O1	671
					12750	114	5	212	428	3				91	1									E2	O1	857
			LO	D. berggrenii	12810	120	2	30	130	12				80	1	4								E2	O1	379
		e			12900	99	25	421	31	13				261	2	65	3							E2	O1	919
			FO	R. rotaria	12930	65	12	219	259	4				33	2	11								E2	O1	706
					12960	90	12	90	100	6				100		8								E2	O1	336
		d			13200	220	12	100	165	10				11		22	3							E2	O1	557
					13230	5	1	6	9								1							E1	O1	27
			FO	A. primus	13260	4	4	162	287	3						1	1							E1	O1	463
Late Miocene	NN11				13290	77	4	14	69	3				31										E2	O1	207
		c			13350	1041	3	31	501					3		31								E2	O2	1599
					13470	59	5	31	188	3				4		25								E2	O2	379
			LO	D. berggrenii	13620	199	13	46	1101					3				2						E2	O2	1367
		b			13650	14		5	5					2		3		1						E1	O1	36
					13820	4	1	4	7															E1	O1	16
			LO	M. convallis	13980	81	12	88	109					3				2	2					E2	O1	333
					14040	101	19	119	521	4				1				4	3					E2	O1	771
		a			14070	91	3	5	88									5						E2	O1	196
					14100	179	1	5	30	3									1					E2	O1	218
			FO	D. quinqueramus	14130	4	5	25	81	3				3										E2	O1	120
					14490	35	7	72	25	3												1		E1	O1	144
					14520	12	12	7	25	1												3		E1	O1	60
	NN10	b			14610	6	13	5	13	3												3		E1	O1	43
					14760	3	1	3	4													3		E2	O1	10
					14790	3	3		3													12		E2	O1	7
			LO	D. bellus	14820	3	3	5	3											1				E2	O1	12
					14850	16		15	1											1		4		E2	O1	33
					14880	3	1		1											3		3		E2	O1	6
					14910			3												1				E2	O1	3
					14940	1	3	3																E2	O1	6
		a			14970	3	1		3											1				E2	O1	7
					15000		2																	E2	O1	2
					15030	4	2	5	2											3		4		E2	O1	19
					15060	3	3	3	1											1		1		E2	O1	9
					15090	10	6	11	8	4										7		12		E2	O1	45
			LO	D. hamatus/C. coalitus	15120	5	5	12	8											7	2	3	1	E2	O1	40
		b			15150	7	5	12	7											4	3	4		E2	O1	39
			FO	D. prepentaradiatus	15180	12	12	12	18											100	7	27	21	E2	O1	164
					15240	3	4	5	3											3			5	E2	O1	15
	NN9				15270	3	12	7	4											12	1		12	E2	O1	38
					15300																			E1	O1	0
		a			15330	3	1	2	3											1			5	E2	O1	10
					15360	21	3	25	4											6	2		21	E2	O1	81
			FO	D. hamatus	15390	5	3	12	3											2	1		12	E2	O1	27
					15420	1	5	3	1											1				E2	O1	14
Middle Miocene	NN8				15450	17	17	36	10				1							3			1	E1	O1	86
					15480	1																		E2	O1	1
			FO	C. coalitus	15510	3		3	3														2	E2	O1	7

Table 1
Well "A"

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Table 2
Well "B"

Age	Nannoplankton Zone	Subzone	Zonal Marker	Depth of Selected Samples (feet) "Well B"	Selected Species																	Etching	Overgrowth	Nannoplankton abundance	Abundance
					Calcidiscus leptoporus	*Dictyococcites productus*	*Sphenolithus neoabies*	*Helicosphaera kamptneri*	*Reticulofenestra minuta*	*Sphenolithus abies*	*Ceratolithus acutus*	*Helicosphaera intermedia*	*Discoaster quinqueramus*	*Reticulofenestra rotaria*	*Discoaster berggrenii*	*Discoaster bergenii*	*Discoaster bollii*	*Discoaster variabilis*	*Discoaster hamatus*	*Discoaster prepentaradiatus*	*Catinaster coalitus*				
Early Pliocene	NN11	b	PR C. acutus	8040		3	2		1	1	1											E2	O1	8	8
				8100	1	8	6	3	6	12	1											E2	O1	37	37
				8250		2			3	1												E2	O1	6	6
Late Miocene		a	LO H. intermedia	8280		9			11	15		1										E2	O1	36	36
				8370	2	8		8	12	9												E2	O1	39	39
				8490	1	7		3	4	13												E2	O1	28	28
	NN11	g	LO D. quinqueramus	8520	1	1		3	11	12			1									E2	O1	29	29
				8580	1	7		1	7	19			4									E2	O1	39	39
				8640	1			8	11	13			6									E2	O1	39	39
		f	LO R. rotaria	8670	3	17		10	31	28		1	6	2								E2	O1	98	98
				8760	1	10		9	13	18			5									E2	O1	56	56
				8850	2	1		3	12	12			3									E2	O1	33	33
		e	LO D. bergrenii	8880	3			2	12	10			10		2							E2	O1	39	39
				8910	3	8		7	9	19			6		1							E2	O1	53	53
				9030	1	9		3	3	15			4		1							E2	O1	36	36
			FO R. rotaria	9180	1	3			2	4				1								E2	O1	11	11
		d		9210		5		1	6	10												E2	O1	22	22
				9480	6	13		7	10	17			3		1							E2	O1	57	57
		c		9660		2			1	2			1									E2	O1	6	6
				####	4	4																E2	O1	8	8
				####		13				3					1							E2	O1	17	17
				####	1	4				3			1									E3	O1	9	9
		b	LO D. bergenii	####	2	17				4			1		1	1						E2	O1	26	26
				####	1	13			2							1						E3	O1	17	17
				####	1	28		2		2			2		2	1						E2	O1	38	38
				####		5				4												E2	O1	9	9
		a		####	2	9				3			1			1						E2	O1	16	16
				####	1	16				3												E2	O1	20	20
			FO D. quinqueramus	####	1	33				27		1	2		1	1						E2	O1	66	66
	NN10	b		####	3	12				3		1										E2	O1	19	19
				####		8																E2	O1	8	8
				####		1				1												E2	O1	2	2
				####		4																E2	O1	4	4
		a	LO D. bollii	####		18				4							1					E2	O1	23	23
				####		2																E2	O1	2	2
				####		1																E3	O1	1	1
	NN9	a	LO D. hamatus	####	1					1									1		1	E3	O1	4	4
				####	4	18		3	1	6							1			1		E3	O1	34	34
			FO D. prepentaradiatus	####	3	2			1	3										1		E2	O1	10	10
				####		4			1	1												E2	O1	6	6
				####	3	9																E2	O1	12	12
			FO D. hamatus	####		8			1	1									1		1	E2	O1	12	12
Middle Miocene	NN8			####	1	3																E3	O1	4	4
				####	2	23		1	12			1										E2	O1	39	39
				####		5			2													E2	O1	7	7
			PR C. coalitus	####		1															1	E2	O1	2	2
				####	4	18		2														E2	O2	24	24

Table 3
Well "C"

Age	Nannoplankton Zone	Subzone	Zonal Marker	Depth of Selected Samples (feet) "Well C"	*Dictyococcites productus*	*Reticulofenestra minutula*	*Ceratolithus rugosus*	*Helicosphaera kamptneri*	*Helicosphaera intermedia*	*Discoaster quinqueramus*	*Reticulofenestra rotaria (cyrcular)*	*Amaurolithus primus*	*Discoaster berggrenii (long), Bukry 1971b*	*Discoaster bergenii (short), Knuttel et al, 1989*	*Discoaster bollii*	*Discoaster hamatus*	*Catinaster coalitus*	*Discoaster prepentaradiatus*	Etching	Overgrowth	Nannoplankton abundance
Early Pliocene	NN13			5030	21	112	1	53											E1	O1	187
				5090	5	32	1	22											E1	O1	60
			FO C. rugosus	5150		54	1	23											E1	O1	78
	NN12	b		5180	18	112		49				1							E1	O1	180
				5450	17	68		44				1							E2	O1	130
				5510		25		8											E1	O1	33
Late Miocene		a	LO H. intermedia	5540		68		21	1			1							E1	O1	91
				5600	39	165		37	2			1							E1	O1	244
				5720	11	198		32	1										E1	O1	242
	NN11	g	LO D. quinqueramus	5750	3	185		26		2									E1	O1	216
				5990	17	231		28	1	17		1							E1	O1	295
				6020		22		13		4									E1	O1	39
				6197	11	2		1		1									E2	O1	15
		f	LO R. rotaria	6200	319	297		16		14	1								E2	O1	647
				6260	269	129		7		6									E2	O1	411
				6290	959	398		49	2	19	1								E2	O1	1428
				6380	319	98		14		5	1								E2	O1	437
		e	LO D. berggrenii	6410	341	119		13		5		1	1						E2	O1	480
				6560	896	259		19		2	1	2	1						E2	O1	1180
			FO R. rotaria	6590	1029	243		24	1	2	2	1							E2	O1	1293
		d		6650	762	242		18		1		2	2						E2	O1	1027
			FO A. primus	6680	559	211		5				1	2						E2	O1	778
		c		6710	98	19		4		1			1						E2	O1	123
				6740	119	26		3					1						E2	O1	149
				6800	139	158		3		1			4						E2	O1	305
		b	LO D. bergenii	6830	159	119		8		1			1	3					E2	O1	291
				6860	39	45		5					1	1					E2	O1	91
				7040	121	58		4		1			1	1					E2	O1	186
		a		7070	34	75		5		1				1					E2	O1	116
				7100	32	52		5		3			1	1					E2	O1	94
			FO D. quinqueramus	7130	78	98		17		2			1	1					E2	O1	197
	NN10	b		7160	22	38		1					1	1					E2	O1	63
				7430	50	4		2											E2	O1	56
				7460	113	6		3										1	E2	O1	122
				7840	39	18		31	1									1	E2	O1	89
				7860	33	32		55	1									1	E2	O1	121
		a	LO D. bollii	7900	45	21		72	2		1				2			1	E2	O1	143
				7980	2	4		5							1			1	E2	O1	12
				8020	4	12		1							1			2	E2	O1	18
				8092	14	4		2							1				E2	O1	21
				8300	2	6		8	1						1				E2	O1	18
	NN9	b	LO D. hamatus	8380	9	3		3								2	2		E2	O1	19
				8462	319	102		8	1									2	E2	O1	430
				8630	2	2		2								1			E2	O1	7
				8780		2		1								1	2		E2	O1	6
				9410				1									1	1	E2	O1	2
			FO D. prepentaradiatus	9460												1		1	E2	O1	1
				9627		1											1		E2	O1	2
				9680		4										1	1		E2	O1	6
				9902				1							1				E2	O1	2
			FO D. hamatus	9910		2										1	1		E2	O1	4
Middle Miocene	NN8			10030		6		1							2		5		E2	O1	13
				10062	2	23		3	1						3		6		E2	O1	38
			PR C. coalithus	10239				2							3		1		E2	O1	6

Table 4
Well "D"

Age	Nannoplankton Zone	Subzone	Zonal Marker		Depth of Selected Samples (feet) "Well D"	Selected Species: *Dictyococcites productus*	*Discoaster brouweri*	*Discoaster pentaradiatus*	*Helicosphaera intermedia*	*Discoaster quinqueramus*	*Reticulofenestra rotaria*	*Amaurolithus primus*	*Discoaster berggrenii*	*Minylitha convalis*	*Discoaster bollii*	*Discoaster hamatus*	*Discoaster prepentaradiatus*	Abundance
Early Pliocene		b			9090	100	12	27										139
					9180	54	16	6				1						77
					9210	60	17	12										89
		a	LO	H. intermedia	9240	11	7	5	1									24
					9270	37	16	12	1									66
					9990	64	24	27	1			1						117
			LO	D. quinqeramus	10050	36	16	22		3								77
Late Miocene	NN11	g			10080	23	11	26		38								96
					10110	44	8	17	1	14								84
					10140	40		18		11								69
		f	LO	R. rotaria	10170	12	42	32		34	1							121
					10200	152	7	17	2	33	2	2						215
		e	LO	D. berggrenii	10230	38	12	2		18	1		2					73
					10290	87	28	1		62	1	1	6					186
					10320	66	13	2	1	87	2	1	3					175
			FO	R. rotaria	10350	56	23	1	1	56	1		3					141
		d			10380	64	9	1		29			1					104
					10440	17	4	3		8			6					38
					10830	50	8			7		1	1					67
					11010	116	24	2		58		1	13					214
					11040	165	30	2		23		1	13					234
			FO	A. primus	11130	23		1		3		1	2					30
		c			11160	125	3	4		2			6					140
					11190	21	2	1		1			2					27
					11280	17		1	1	3			2				2	24
		b	LO	D. bergenii	11310	3	2			1			2					8
					11370	7												7
					11430					1			1					2
		a	LO	M. convalis	11490	23	5	1		5			3	1				38
					11520	14	2						1	1				18
					11700	65	1	2	1	2				1				72
					11730	8	2	1		3				1				15
			FO	D. quinqueramus	11790	12	1			2								15
	NN10	b			11970	72	2	1	1								1	76
					12000	10	1	1	1								1	13
					12330	13		1									1	14
					12420	12												12
		a	LO	D. bolli	12630	15	2	1	1						1		1	20
					12900	43		1						1	1		1	46
					13080	6												6
	NN9	b	LO	D. hamatus	13110	57	35	4	1						1	3	1	101
					13140	9									1	2	1	12
					13170	2										1		3
			PR	D. hamatus/D. prepentaradiatus	13200	7										1	1	8

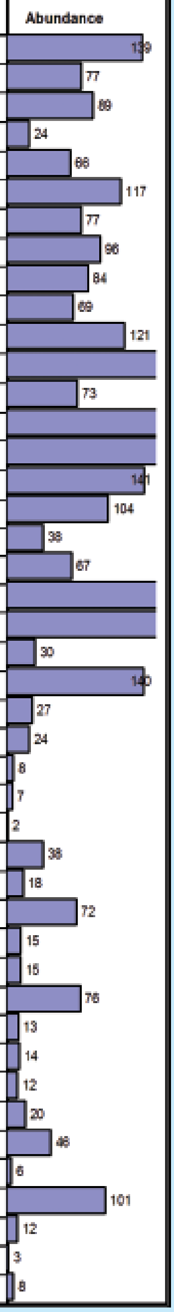

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Table 5
Well "E"

Age	Nannoplankton Zone	Subzone	Zonal Marker	Depth of Selected Samples (feet) "Well E"	*Dictyococcites productus*	*Discoaster brouweri*	*Discoaster surculus*	*Ceratolithus rugosus*	*Discoaster asymmetricus*	*Ceratolithus acutus*	*Coccolithus pelagicus*	*Sphenolithus moriformis*	*Helicosphaera intermedia*	*Discoaster quinqueramus*	*Reticulofenestra rotaria*	*Discoaster berggrenii*	*Amaurolithus primus*	*Discoaster bergenii*	*Discoaster bollii*	*Discoaster prepentaradiatus*	*Discoaster hamatus*	*Catinaster coalitus*	Nannoplankton abundance	Preservation: Etching	Preservation: Overgrowth
EARLY PLIOCENE	NN13			6300	3																		3	E1	O2
				6330	22	1	1	1															26	E1	O2
			FO C. rugosus	6360		12		1	1														14	E1	O2
	NN12	b	LO C. acutus	6390	8	3	1			1													13	E1	O2
				6420		1				1													2	E1	O2
				6510	7					1													8	E1	O2
				6780	17	3											1						21	E1	O1
				7530	16		1										1						18	E1	O2
Late Miocene		a	LO H. intermedia	7560	38	2							1										41	E1	O2
				7620	7	1							1										9	E1	O1
				7650	21	4							1										26	E1	O1
				7980	13	2							2										17	E1	O1
	NN11	g	LO D. quinqueramus	8160	13									3									16	E1	O1
				8310	16	1	1						1	17									36	E2	O1
				8340	91	2						3		16									110	E2	O1
				8370	241	1							2	11									255	E2	O1
		f	LO R. rotaria	8430	42						1			3	4								50	E2	O1
				8460	159						1			2	1		1						164	E2	O1
				8520	341	6						2		28	2								377	E2	O1
				8550	436	16					1	3	2	33	3								496	E2	O1
				8730	179	7	1				1		1	18	1								208	E2	O1
		e	LO D. berggrenii	8790	19	1					1			8		2							31	E2	O1
				8820	12	2					1			11		3	1						30	E2	O1
				8850	42	8	1				3		2	61	2	17							136	E2	O1
				8880	101	2						1		6		6							116	E2	O1
			FO R. rotaria	8910	279	4	1				1	3		28	1	18							335	E2	O1
		d		8970	439									4		2	1						446	E2	O1
				9060	88	2						3		5		1							100	E2	O1
				9180	559	1					2	6	2	32		19	2						623	E2	O1
				9300	298						3	3	1	12		4	1						322	E2	O1
			FO A. primus	9330	51						2	2		2		7	1						65	E2	O1
		c		9360	5																		5	E2	O1
				9390	22																		22	E2	O1
				9630	9							1											10	E2	O1
		b	LO D. bergenii	9660	33							1		1				1					36	E2	O1
				9690	99							1		2		1		2					105	E2	O1
				9750	12	1						1		3		1		3					21	E2	O1
			FO D. quinqueramus	9900	55							2	1	2		1		1					62	E2	O1
	NN10	b		11250	10							1						1					12	E2	O1
				11400	42							4						1					47	E2	O1
				11850	6							2											8	E2	O1
		a	LO D. bollii	11880	26							2							1				29	E2	O1
				11910	9														1				10	E2	O1
				12270	16							4							1				21	E2	O1
	NN9	b	LO D. hamatus/C. coalitus	12390								8									1	1	10	E2	O2
				12750	1	3						8								1	1		14	E2	O1
				12870	5	12						7								2			26	E2	O1
				13200	6						2	2								1			11	E2	O1
				13305							1	3								1			5	E2	O1
				13470	4	16					3	7	1						2	6	5		44	E2	O1
			FO D. prepentaradiatus	14010								2								1	1		4	E2	O1
		a		14250	2							4									1		7	E2	O1
				14310								2											2	E2	O1
				14550								3									1		4	E2	O1
			FO D. hamatus	14580								2									1		3	E2	O1
Middle Miocene	NN8			14670								2											2	E2	O1
				14730								4											4	E2	O1
				14790	2							4										1	7	E2	O1
			FR C. coalitus	14820	1							4										1	6	E2	O1

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NN 11a (indicated by the FO of *Discoaster quinqueramus* at the bottom and the LO of *Minilitha convalis* at the top), Subzone NN11b (characterized by the LO of *Minilitha convalis* at the bottom and the LO of *Discoaster bergenii* at the top), Subzone NN11c (indicated by the LO of *Discoaster bergenii* at the bottom and the FO of *Amaurolithus primus* at the top), Subzone NN11d (characterized by the FO of *Amaurolithus primus* at the bottom and the FO of *Reticulofenestra rotaria* at the top), Subzone NN11e (marked by the FO of *Reticulofenestra rotaria* at the bottom and the LO of *Discoaster berggrenii* at the top), Subzone NN11f (characterized by the LO of *Discoaster berggrenii* at the bottom and the LO of *Reticulofenestra rotaria* at the top), and Subzone NN11g (indicated by the LO of *Reticulofenestra rotaria* at the bottom and the LO of *Discoaster quinqueramus* at the top).

Zone NN12

The bottom of this zone is marked by the LO of *Discoaster quinqueramus*, whilst its top is indicated by the FO of *Ceratolithus rugosus*. This zone can be subdivided into subzones NN12a and NN12b. Subzone NN12a is indicated by the LO of *Discoaster quinqueramus* at the bottom and the LO of *Helicosphaera intermedia* at the top. Subzone NN12b is characterized by the LO of *Helicosphaera intermedia* at the bottom and the FO of *Ceratolithus rugosus* at the top. The boundary of subzone NN12a/NN12b is assumed coincide with the top of Late Miocene age. Due to very rare occurrence of *Ceratolithus rugosus* in many sections, the top of zone NN12 is difficult to be defined precisely. The alternative of zonal markers for the top of zone NN12 are the LO of *Ceratolithus acutus* and *Discoaster intercalaris*. However, the LO of *Discoaster intercalaris* tend to be little bit younger.

Photograph and description of the index species can be seen in Plate 1 – 5. The simplified results of atic nannoplankton studies. There is data in some unpublished reports that *Discoaster bergrenii* can be separated into long arms, short arm-1 and short arms-2. This is confusing because the shorter arms of *Discoaster berggrenii* is *Discoaster bergenii*, and actually, the variance above is not caused by evolutionary process, but impact of depositional, preservation and laboratory process.

IX. ACKNOWLEDGEMENT

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