RIASSUNTO

Il valore stratigrafico dei nannofossili calcarei a forma di stella del genere *Discoaster* è ben noto: secondo le scale biozonali correnti, nel Cenozoico si possono riconoscere da 17 a 25 intervalli stratigrafici basati sugli eventi a *Discoaster*. Spesso l'utilizzazione pratica di queste scale viene tuttavia limitata dalla rarità degli esemplari marker e dalla cattiva preservazione delle associazioni, che non consentono una identificazione tassonomica precisa dei discoaster. Per ovviare a questa difficoltà viene proposto un metodo quantitativo basato sulla variazione del numero di braccia dei discoaster nel corso dei tempi. Esso permette di considerare tutti gli individui presenti qualunque sia il loro stato di conservazione.

Sono state effettuate analisi quantitative su fanghi carbonatici oceanici di diverse regioni: Pacifico centrale (sito DSDP 317B), Oceano Indiano (siti DSDP 213, 216, 219, 223 e 245-245A; MD-40-MACAMO sito di dragaggio DR-03), Atlantico nord-occidentale (siti DSDP 390A e ODP 627B) e Trinidad. I 148 campioni scelti sono rappresentativi delle principali associazioni a *Discoaster* note nell'intervallo di presenza del gruppo (Paleocene medio - Pliocene terminale). Per i campioni del Paleocene e dell'Eocene, dove le associazioni sono abbastanza ben preservate da consentire l'identificazione tassonomica precisa di ogni asterolite, la ripartizione del numero di braccia è comparata alle specie di *Discoaster* presenti.

I risultati ottenuti sono simili nelle diverse regioni studiate e coerenti con le tendenze evolutive generali del genere *Discoaster* descritte in letteratura. Essi indicano che, fra le molteplici specie validamente pubblicate, solo un piccolo numero è sufficientemente abbondante da influenzare la ripartizione del numero di braccia nella popolazione di *Discoaster*. Viene proposta una biozonazione del Cenozoico comprendente 17 biozone basate esclusivamente sulle variazioni del numero di braccia degli asteroliti. Le zone sono contraddistinte da un sistema di numerazione (D-CP/CN) direttamente ispirato a quello di Bukry. Questa nuova zonazione ha il vantaggio di utilizzare un gruppo di nannofossili unico e frequente e di non richiedere una attribuzione tassonomica dettagliata. Essa sarà dunque particolarmente interessante per correlare serie deposte in differenti condizioni paleoambientali o sedimenti contenenti associazioni mal conservate.

RÉSUMÉ

La valeur stratigraphique des nannofossiles calcaires en forme d'étoile du genre *Discoaster* est bien connue: selon les échelles de biozones habituelles, ce groupe permet à lui seul de subdiviser le Cénozoïque en 17 à 25 intervalles. Toutefois, l'utilisation pratique de ces échelles est souvent limitée par la rareté des spécimens marqueurs identifiables, et par la trop mauvaise préservation des associations, qui interdit une identification taxonomique précise des *Discoaster*. Pour tourner cette difficulté, une méthode quantitative est proposée, fondée sur les variations du nombre de bras des *Discoaster* au cours du temps. Elle permet de prendre en compte tous les individus présents, quel que soit leur état de conservation.

Des analyses quantitatives ont été effectuées sur des boues carbonatées océaniques de différentes régions: Pacifique central (site DSDP 317B), Océan Indien (sites DSDP 213, 216, 219, 223 et 245-245A; site de dragage MD-40-MACAMO DR03), Atlantique nord-ouest (sites DSDP 390A et ODP 627B) et Trinidad. Les 148 échantillons choisis représentent les principales associations de *Discoaster* connues dans l'intervalle de présence du groupe (Paléocène moyen-Pliocène terminal). Pour les échantillons du Paléocène et de l'Eocène, où les associations sont assez bien préservées pour permettre l'identification taxonomique précise de chaque astérolithe, la répartition des nombres de bras est comparée aux espèces de *Discoaster* présentes.

Les résultats obtenus sont similaires pour les différentes régions étudiées, et cohérents avec les tendances évolutives générales des *Discoaster* décrites dans la littérature. Ils indiquent que, parmi les multiples espèces validement publiées, seul un petit nombre est suffisamment abondant pour influencer la répartition des nombres de bras dans la population de *Discoaster*. Une biozonation du Cénozoïque est proposée, comprenant 17 biozones exclusivement fondées sur les variations du nombre de bras des astérolithes. Le système de numérotation adopté pour les zones (D-CP/CN) est directement inspiré de celui de Bukry. Cette nouvelle zonation a l'avantage d'utiliser un groupe de nannofossiles calcaires unique et fréquent, et de ne nécessiter aucune distinction taxonomique délicate. Elle sera donc particulièrement intéressante pour corréler des séries déposées dans des conditions différentes de paléoenvironnement, ou des sédiments livrant des associations mal préservées.

INTRODUCTION

The asteroliths (*Discoaster* and other related genera, such as *Catinaster* and *Discoasteroides*; see Loeblich and Tappan (1966-1973), Van Heck (1979-1982) and Steinmetz (1983-1989) for taxonomical references), accurately described first by Tan Sin Hok (1927), have been widely used as biostratigraphical markers since the pioneering work of Bramlette and Riedel (1954). Their abundance in many marine Cenozoic sediments, partly due to either their particular resistance to dissolution (Roth and Thierstein, 1972; Bukry, 1973a, 1981a; Wise, 1977), or to their relatively large size and easily identifiable shape (Prins, 1971), explain this successful use. From their first appearance in the late Paleocene to their abrupt decrease in abundance near the Plio-Pleistocene boundary, the discoaster assemblages show many successive variations in ray numbers and morphology, providing suitable marker events (BUKRY, 1971a). PRINS (1971) established a zonation based on discoasters only. The MARTINI's and BUKRY's biozonations (MARTINI, 1971; BUKRY, 1973b, codified by OKADA and BUKRY, 1980, with addition of a supplementary subzone in BUKRY, 1981b), recognize seventeen and twenty five intervals, respectively, based on discoaster events. Finer stratigraphical subdivisions are proposed by different authors (THEODORIDIS, 1984; DRIEVER, 1981, 1988).

The biostratigraphical application of discoaster events is however often limited by the low abundances of the marker specimens. Moreover, the asterolith taxonomy is rather complex, with more than 300 species described (see catalogues of LOEBLICH and TAPPAN, 1966-73; VAN HECK, 1979-82 and STEINMETZ, 1983-89; AUBRY, 1984), which are not always clearly defined (THEODORIDIS, 1984; PERCH-NIELSEN, 1985; JANIN, 1987; DRIEVER, 1988). Part of the difficulties originates from the common occurrence of transitional specimens among the typical ones (BRAMLETTE and SULLIVAN, 1961), together with the possibility of considerable morphological change due to dissolution and overgrowth during diagenesis (ROTH and THIERSTEIN, 1972; ADELSECK *et al.*, 1973; MARTINI, 1976; WISE, 1977; BUKRY, 1981b; JANIN, 1987). Many asteroliths cannot be objectively identified and DRIEVER (1988) reports that 20 to 50% of the 6-rayed specimens cannot be determined accurately in fairly well preserved associations from the Mediterranean Pliocene. Diagenetically altered sediments may provide assemblages where the discoasters are dominant but cannot be determined at the species level: see for instance, the case of the calcareous nannofossil oozes associated with the manganese nodule facies of the northeastern Equatorial Pacific (JANIN, 1987, 1988, 1989).

The aim of this paper is to propose a quantitative biostratigraphical approach based on counts of discoaster ray numbers. The method gives objective data, whatever is the preservation state of the assemblages. Consequently, it may be applied to a large variety of oceanic sediments.

METHODS AND MATERIAL

SELECTION OF THE ASTEROLITH RAY NUMBER AS EVOLUTIONARY TREND INDEX

The Cenozoic asteroliths constitute a distinct nannofossil group, in which the main variations concern the size, the ray number, the outline (morphology of the ray tip, length of the rays with respect of the central area, ray thickness), the ray bending, the presence of a central knob and the surface ornamentation (STRADNER and PAPP, 1961; BUKRY, 1971a; AUBRY, 1984; PERCH-NIELSEN, 1985). The general evolutionary trend of discoaster morphology from the Paleocene to the Pleistocene is the decrease of the ray number and the production of more delicate morphotypes incorporating a smaller amount of calcite (BUKRY, 1971a; PRINS, 1971). The three main differentiating features (the size, the ray number and the outline) show independent variation, and a given assemblage generally contains small and large asteroliths with variable outline for the same ray number, together with small and large specimens with identical ray tip morphology, but variable ray number (Fig. 1 and JANIN, 1987). Consequently any taxonomical classification of discoasters first calls for a hierarchical choice between the various characters available.

The discoasters usually occur as particles disseminated in the sediments. As with many other calcareous nannofossil groups, discoasters can only be classified parataxonomically, using an arbitrarily defined hierarchy of the characters. The so-called "*Discoaster* species" represent convenient morphotype groupings rather than biological species. The first systematic scheme, introduced by TAN SIN HOK (1927) and followed by earlier authors (DEFLANDRE, 1934), considered the

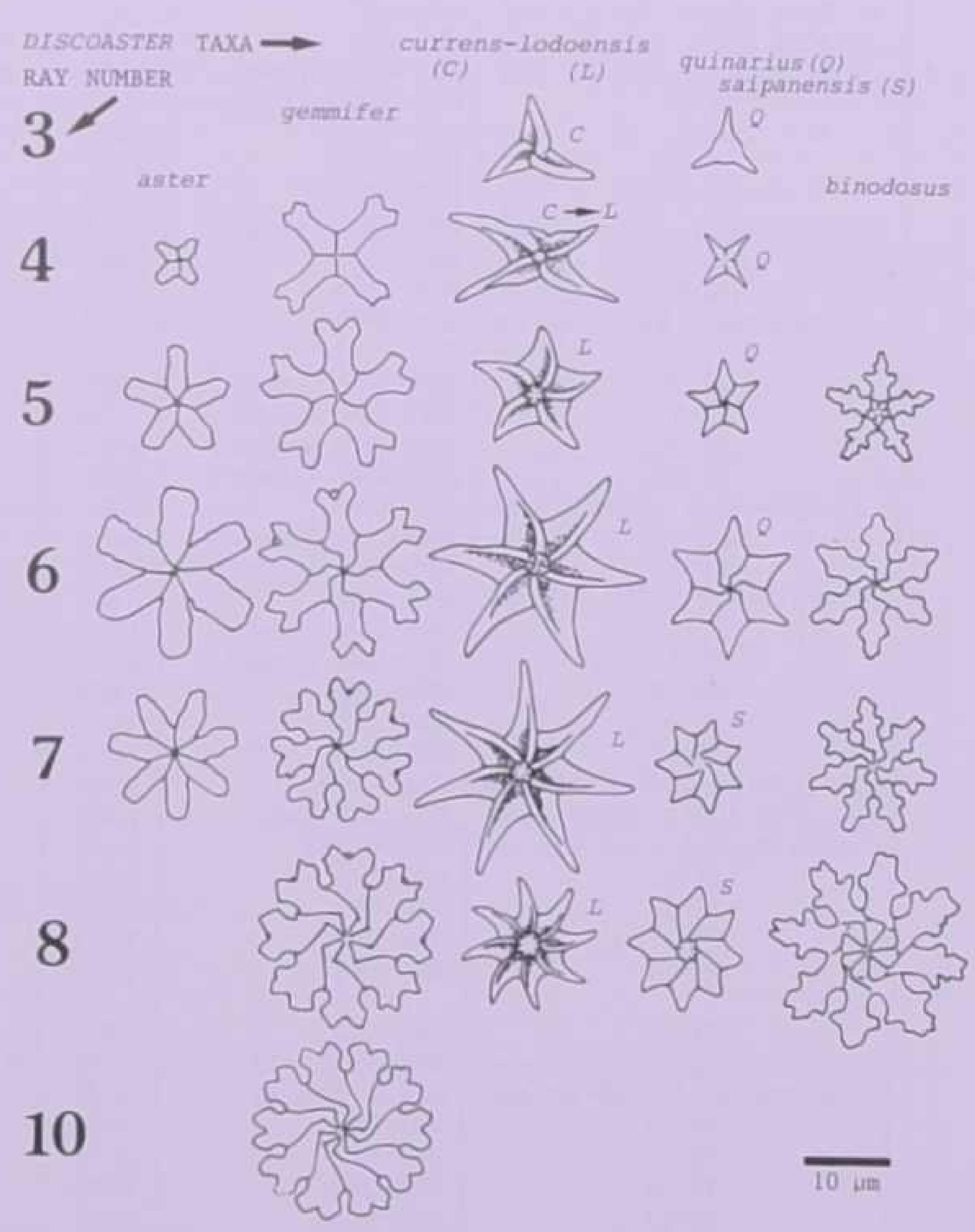

FIG. 1 - Morphological variability of discoasters: example of some of the asteroliths illustrated by STRADNER and PAPP (1961, Pls. 1, 4-5, 8-9, 22-23 and 25-26). Note the independent variation of the asterolith outline and ray number.

TABLE 1 - Age of the samples studied, and results of discoaster ray number analyses. (For the Trinidad samples, the 3-rayed asteroliths are counted with the 6-rayed ones). See Fig. 2 and Appendix for site location

SAMPLE	BIOZONE	NUMB. OF ANALYSED ASTEROL.	RAY NUMBER OF ASTEROLITHS (percentage of different types) 3	4	5	6	7	8	9	10	11	12
33-317B-2-1 (53-37 cm)	NN17-CN12c	429	1.86	0.23	5.83	91.84	0.23	-	-	-	-	-
101-627B-3H-2 (50-52 cm)	NN17-CN12c	280	1.07	1.79	28.93	68.21	-	-	-	-	-	-
101-627B-3H-5 (50-52 cm)	NN17-CN12c	150	-	0.67	45.33	54.0	-	-	-	-	-	-
33-317B-2-2 (110-111 cm)	NN16-CN12a	376	0.80	1.86	46.28	51.06	-	-	-	-	-	-
101-627B-4H-2 (25-27 cm)	NN16-CN12a	166	1.20	4.82	46.39	47.59	-	-	-	-	-	-
33-317B-3-1 (110-111 cm)	NN16-CN12a	421	0.24	2.14	21.85	75.77	-	-	-	-	-	-
101-627B-4H-6 (25-27 cm)	NN16-CN12a	22	insufficient number of asteroliths encountered									
33-317B-3-5 (85-86 cm)	NN16-CN12a	497	1.41	2.82	32.80	62.98	-	-	-	-	-	-
101-627B-5H-2 (50-52 cm)	NN16-CN12a (top)	280	0.36	2.50	44.29	52.86	-	-	-	-	-	-
101-627B-5H-4 (50-52 cm)	NN15-CN11b	348	2.59	8.33	29.02	60.06	-	-	-	-	-	-
33-317B-4-4 (85-86 cm)	NN15-CN11	653	0.77	-	18.68	80.55	-	-	-	-	-	-
101-627B-5H-6 (50-52 cm)	NN14-CN10d	280	0.71	-	21.79	77.50	-	-	-	-	-	-
101-627B-6H-2 (50-52 cm)	NN14-CN10d	280	0.36	0.36	59.64	39.64	-	-	-	-	-	-
101-627B-6H-4 (50-52 cm)	NN14-CN10d	280	1.43	1.43	61.07	36.07	-	-	-	-	-	-
101-627B-7H-1 (50-52 cm)	NN14-CN10d (?)	212	-	0.47	61.79	37.74	-	-	-	-	-	-
33-317B-5-2 (84-85 cm)	NN13-CN10c	798	-	0.13	15.79	84.09	-	-	-	-	-	-
33-317B-6-6 (85-86 cm)	NN12/13-CN10bc	597	-	-	8.54	91.46	-	-	-	-	-	-
101-627B-7H-3 (50-52 cm)	NN12-CN10a	280	1.07	-	51.43	47.50	-	-	-	-	-	-
101-627B-7H-5 (50-52 cm)	NN12-CN10a	281	-	0.36	44.13	55.52	-	-	-	-	-	-
33-317B-7-4 (85-86 cm)	NN12-CN10a	493	-	-	9.33	90.67	-	-	-	-	-	-
MD40/MACAMO-M84-DR03-1'	NN11-CN9b (top)	1158	-	-	56.65	43.35	-	-	-	-	-	-
101-627B-8H-1 (50-52 cm)	NN11-CN9	127	2.40	1.57	14.17	81.10	0.79	-	-	-	-	-
33-317B-9-2 (85-86 cm)	NN11-CN9b	328	0.61	0.61	28.66	70.12	-	-	-	-	-	-
101-627B-8H-3 (50-52 cm)	NN11-CN9	291	-	0.34	26.46	72.85	0.34	-	-	-	-	-
101-627B-8H-5 (50-52 cm)	NN11-CN9	280	-	0.71	21.43	77.50	0.36	-	-	-	-	-
101-627B-9H-1 (50-52 cm)	NN11-CN9	280	0.36	0.71	14.29	84.64	-	-	-	-	-	-
101-627B-9H-3 (50-52 cm)	NN11-CN9	280	0.36	-	13.21	86.43	-	-	-	-	-	-
33-317B-10-5 (91-93 cm)	NN11-CN9a	280	-	-	11.07	88.93	-	-	-	-	-	-
101-627B-9H-5 (50-52 cm)	NN11-CN9	283	-	0.71	17.67	80.57	0.71	0.35	-	-	-	-
101-627B-9H-6 (50-52 cm)	NN11-CN9	555	0.18	-	5.41	93.51	0.90	-	-	-	-	-
101-627B-10H-4 (50-52 cm)	NN10-CN8b	1148	-	-	5.23	94.08	0.61	0.09	-	-	-	-
101-627B-10H-5 (50-52 cm)	NN10-CN8a	443	-	0.23	5.42	94.13	0.23	-	-	-	-	-
101-627B-11H-1 (50-52 cm)	NN10-CN8a	392	-	-	3.06	95.92	1.02	-	-	-	-	-
101-627B-11H-3 (50-52 cm)	NN10-CN8a	1199	0.17	-	1.25	98.42	0.08	0.08	-	-	-	-
101-627B-11H-5 (50-52 cm)	NN10-CN8a	1087	0.37	0.09	2.58	96.60	0.37	-	-	-	-	-
101-627B-12H-1 (50-52 cm)	NN10-CN8a	474	0.42	-	2.53	96.20	0.42	0.42	-	-	-	-
33-317B-12-2 (85-86 cm)	NN9-CN7b (top)	388	-	-	7.99	92.01	-	-	-	-	-	-
101-627B-12H-5 (50-52 cm)	NN9-CN7	1072	0.19	0.19	2.61	96.55	0.37	0.09	-	-	-	-
33-317B-13-3 (93-94 cm)	NN8-CN6	1331	-	-	3.76	96.09	0.15	-	-	-	-	-
33-317B-14-2 (85-86 cm)	NN7-CN5b (top)	1534	-	-	5.08	94.85	0.07	-	-	-	-	-
TR-9	NN7-CN5b (top)	1142	-	-	16.64	82.92	0.26	0.09	-	0.09	-	-
TR-8	NN7-CN5b	2421	-	-	5.45	94.26	0.17	-	0.12	-	-	-
TR-27	NN7-CN5b	1247	-	-	1.60	98.08	0.16	-	0.08	0.08	-	-
TR-6	NN7-CN5b	3368	-	0.18	2.67	97.00	0.12	0.03	-	-	-	-
33-317B-16-1 (10-11 cm)	NN7-CN5b (base)	1261	-	-	2.93	97.07	-	-	-	-	-	-
TR-26	NN7-CN5b	1669	-	-	3.24	96.46	0.18	-	-	0.12	-	-
TR-5	NN6-CN5a	1309	-	0.15	2.90	96.79	0.15	-	-	-	-	-
33-317B-16-5 (109-110 cm)	NN6-CN5a	1292	-	-	2.79	96.98	0.23	-	-	-	-	-
TR-25	NN5-CN4 (upper)	1686	-	-	1.72	98.10	0.12	-	0.06	-	-	-
TR-7	NN5-CN4 (upper)	760	-	-	1.58	98.29	0.13	-	-	-	-	-
TR-24	NN5-CN4 (upper)	2452	-	0.12	3.34	96.08	0.41	-	-	0.04	-	-
TR-12	NN5-CN4 (lower)	1827	-	-	2.85	96.88	0.27	-	-	-	-	-
33-317B-18-2 (35-36 cm)	NN5-CN4	1312	0.15	-	2.36	97.33	0.15	-	-	-	-	-
TR-11	NN5-CN4 (lower)	1445	-	0.07	2.77	96.89	-	0.07	0.14	-	0.07	-
TR-10	NN5-CN4 (lower)	1303	-	-	1.38	98.62	-	-	-	-	-	-
101-627B-16H-5 (50-52 cm)	NN5-CN4	908	0.44	-	1.76	97.69	0.11	-	-	-	-	-
TR-13	NN5-CN4 (lower)	1324	-	-	2.27	97.73	-	-	-	-	-	-
TR-4	NN5-CN4 (base)	1555	-	-	1.99	97.81	0.19	-	-	-	-	-
TR-23	NN4-CN3	2118	-	-	2.74	96.84	0.38	-	-	-	0.05	-
TR-3	NN4-CN3	3417	-	0.06	3.04	96.49	0.41	-	-	-	-	-
TR-22	NN4-CN3	1940	-	-	2.68	96.80	0.46	0.05	-	-	-	-
33-317B-19-1 (110-111 cm)	NN2/4-CN3	1091	-	0.18	5.77	93.58	0.46	-	-	-	-	-
101-627B-17X-3 (50-52 cm)	NN4-CN3 (top)	1392	-	0.22	3.74	95.26	0.79	-	-	-	-	-
33-317B-19-4 (115-116 cm)	NN2/4-CN3	1120	-	0.27	7.23	91.34	1.16	-	-	-	-	-
TR-2	NN4-CN3	1515	-	-	3.56	95.64	0.79	-	-	-	-	-
TR-21	NN4-CN3	1413	-	-	3.33	96.11	0.50	-	-	0.07	-	-
TR-1	NN4-CN3	1643	-	-	3.41	96.17	0.24	0.06	-	0.06	-	0.06
TR-20	NN4-CN3	2122	-	-	4.24	95.05	0.71	-	-	-	-	-
TR-15	NN3-CN2	1309	-	0.08	4.35	93.96	1.53	-	-	0.08	-	-
101-627B-18X-1 (50-52 cm)	NN3/4-CN1c/3	653	0.15	-	4.59	94.18	1.07	-	-	-	-	-
33-317B-20-1 (59-60 cm)	NN2/4-CN1c/2	1135	-	0.18	3.79	95.33	0.70	-	-	-	-	-
TR-16	NN3-CN2	2468	-	0.04	4.70	94.21	1.01	0.04	-	-	-	-
TR-17	NN3-CN2	2079	-	0.10	7.17	91.34	1.39	-	-	-	-	-
TR-18	NN2-CN2	2098	-	-	3.05	95.90	0.95	0.05	0.05	-	-	-
TR-19	NN2-CN1c	2168	-	0.05	5.77	92.48	1.66	-	-	0.05	-	-
101-627B-19X-4 (50-52 cm)	NN2-CN1c	978	0.10	-	3.89	95.30	0.72	-	-	-	-	-
33-317B-20-5 (130-131 cm)	NN1-CN1b	1132	-	0.18	3.27	95.85	0.71	-	-	-	-	-
33-317B-22-2 (59-60 cm)	NN1-CN1a	1096	-	0.09	4.56	93.89	1.46	-	-	-	-	-
TR-14	NN1-CN1a (CP19b?)	1167	-	-	2.40	96.49	1.03	-	-	-	0.08	-
33-317B-23-3 (84-85 cm)	NN1-CN1a	1181	-	0.34	4.83	93.40	1.44	-	-	-	-	-
33-317B-24-5 (88-89 cm)	NN1-CN1a	1160	-	-	5.86	93.36	0.78	-	-	-	-	-

TABLE 1 - (*continued*)

SAMPLE	BIOZONE	NUMB. OF ANALYSED ASTEROL.	RAY NUMBER OF ASTEROLITHS (percentage of different types) 3	4	5	6	7	8	9	10	11	12	13
33-317B-26-1 (104-105 cm)	NP25-CP19b	1121	-	0.27	7.85	89.92	1.96	-	-	-	-	-	-
TR-32	NP25-CP19b	2277	-	0.09	2.28	96.31	1.23	-	-	0.04	0.04	-	-
TR-31	NP25-CP19b	1987	-	0.10	2.01	96.07	1.51	0.10	0.10	0.05	-	0.05	-
33-317B-27-5 (35-36 cm)	NP25-CP19b	1437	-	-	4.94	94.29	0.76	-	-	-	-	-	-
33-317B-29-1 (75-76 cm)	NP24-CP19a	1163	-	0.09	5.85	93.21	0.86	-	-	-	-	-	-
TR-30	NP24-CP19a	1409	-	-	4.26	93.47	1.99	0.07	0.14	0.07	-	-	-
33-317B-30-5 (115-116 cm)	NP24-CP19a	1143	-	-	5,86	92.30	1.75	0.87	-	-	-	-	-
TR-29	NP23-CP18	1960	-	0.15	3.21	95.31	1.17	-	0.05	0.05	-	0.05	-
23-219-15-2 (63-67 cm)	NP23-CP17	305	-	-	8.52	87.87	1.97	-	1.31	0.33	-	-	-
33-317B-31-5 (115-116 cm)	NP23-CP17	1177	-	0.25	11.81	86.58	1.36	-	-	-	-	-	-
23-219-15-5 (133-137 cm)	NP23-CP17	280	-	-	13.93	81.79	3.57	0.36	0.36	-	-	-	-
33-317B-33-3 (115-116 cm)	NP23-CP17	560	-	0.18	30.36	68.57	0.89	-	-	-	-	-	-
33-317B-34-4 (110-111 cm)	NP22-CP16c	1218	-	0.49	14.86	82.76	1.89	-	-	-	-	-	-
33-317B-35-1 (80-81 cm)	NP21-CP16	280	-	-	21.79	67.50	5.0	0.36	2.14	2.50	0.71	-	-
33-317B-35-5 (45-46 cm)	NP21-CP16	560	-	0.36	28.04	68.75	2.50	0.18	0.18	-	-	-	-
23-223-31-5 (31-36 cm)	NP21-CP16b	280	-	-	46.43	50.71	1.79	0.36	-	0.71	-	-	-
23-219-16-4 (72-76 cm)	NP21-CP16b	280	-	-	70.36	27.86	1.43	-	-	0.36	-	-	-
33-317B-36-1 (35-36 cm)	NP18/20-CP15 (top)	280	-	-	26.43	38.57	11.79	4.29	9.64	6.43	2.86	-	-
33-317B-36-4 (80-81 cm)	NP18/20-CP15	280	-	-	31.79	23.57	7.14	3.57	16.79	13.93	3.21	-	-
23-219-17-5 (14-18 cm)	NP18/20-CP15	280	-	-	13.21	18.93	21.07	2.50	18.21	16.79	8.21	1.07	-
33-317B-37-4 (85-86 cm)	NP18/20-CP15	280	-	-	28.57	20.0	21.07	6.79	13.21	8.21	1.79	0.36	-
23-223-32-1 (96-100 cm)	NP18/20-CP15	560	-	-	7.86	22.86	28.04	8.75	19.46	11.96	1.07	-	-
23-219-18-4 (69-73 cm)	NP17/18 boundary CP14b/15a bound.	280	-	0.36	7.50	22.86	42.50	8.21	12.50	5.0	1.07	-	-
23-223-32-4 (117-121 cm)	NP17-CP14b	280	-	-	3.57	25.71	28.57	9.64	14.29	14.29	3.93	-	-
33-317B-38-4 (85-86 cm)	NP17-CP14b	280	-	-	7.50	34.64	25.71	6.07	15.36	8.93	1.79	-	-
23-219-19-2 (79-83 cm)	NP17-CP14b	280	-	-	2.86	35.71	32.14	4.29	6.07	13.93	3.93	0.71	0.36
23-219-19-5 (128-132 cm)	NP17-CP14b	280	-	0.36	2.50	14.29	9.29	15.0	21.79	20.71	14.64	1.07	0.36
23-223-33-2 (112-117 cm)	NP17-CP14b	560	-	0.18	0.71	10.89	5.36	13.04	24.11	24.64	17.14	3.75	0.18
33-317B-39-4 (84-85 cm)	NP16-CP14a	280	-	-	1.79	11.43	7.14	20.36	33.57	16.79	8.21	0.71	-
23-219-20-3 (65-69 cm)	NP16-CP14a	280	-	1.07	2.50	8.21	5.0	15.0	18.57	30.71	12.50	5.36	1.07
33-317B-40-3 (85-86 cm)	NP16-CP14a (base)	279	-	-	3.23	19.0	7.53	20.79	26.16	17.20	5.38	0.72	-
23-219-20-6 (85-89 cm)	NP15-CP13c	275	-	3.27	2.55	8.36	1.45	9.09	30.91	33.09	6.91	1.82	0.73
			(+ 14 rays: 0.36% , 17 rays: 0.36%, 18 rays: 0.73%, and 20 rays: 0.36%)										
23-219-21-3 (65-69 cm)	NP15-CP13c	273	-	0.73	2.20	8.79	4.03	4.76	17.22	39.56	20.51	1.83	0.37
25-245A-6-3 (132-136 cm)	NP15-CP13c (?)	200	-	-	4.50	38.0	5.0	11.0	20.0	7.0	6.50	2.50	1.0
					(+ 14 rays: 1.50%, 15 rays: 1.50%, and 17 rays: 1.50%)								
25-245-3-4 (119-123 cm)	NP15-CP13b (?)	198	-	-	2.53	28.79	9.09	18.69	21.21	13.13	5.56	1.01	-
23-223-34-2 (38-42 cm)	NP15-CP13bc (?)	274	-	0.36	2.19	13.87	10.22	14.23	15.33	20.07	15.33	5.84	2.55
44-390A-4-3 (113-119 cm)	NP15-CP13b	474	-	0.42	3.59	23.21	4.22	3.80	16.46	25.32	18.14	3.80	0.42
					(+ 15 rays: 0.21%, 17 rays: 0.21%, and 19 rays: 0.21%)								
44-390A-4-5 (96-101 cm)	NP15-CP13b	280	-	0.71	3.21	31.43	7.86	3.57	16.07	22.86	11.07	2.14	0.36
					(+ 21 rays: 0.36%, and 23 rays: 0.36%)								
44-390A-4-6 (115-120 cm)	NP15-CP13b	262	-	-	1.91	34.73	14.50	5.34	9.54	18.70	9.92	3.44	0.38
			(+ 18 rays: 0.38%, 21 rays: 0.38%, 26 rays: 0.38%, and 27 rays: 0.38%)										
33-317B-42-1 (75-76 cm)	NP15-CP13 (a ?)	276	-	-	1.45	11.96	16.30	21.01	24.28	16.30	7.61	0.73	0.36

SAMPLE	BIOZONE	NUMB. OF ANALYSED ASTEROL.	RAY NUMBER OF ASTEROLITHS (percentage of different types) 3	4	5	6	7	8	9	10	11	(16-35 rays: see below) 12	13	14	15
33-317B-42-3 (110-111 cm)	NP14-CP12b (top)	280	-	0.36	20.0	3.93	6.07	13.57	15.36	23.21	15.0	2.50	-	-	-
44-390A-4-CC	NP14-CP12b (top)	279	-	0.72	21.15	13.98	7.17	11.83	10.75	17.56	11.83	2.87	-	-	-
25-245A-7-2 (136-140 cm)	NP14-CP12a (top)	280	-	-	8.93	26.43	11.43	9.29	5.0	11.43	16.43	7.50	1.43	0.36	-
23-219-25-1 (125-130 cm)	NP13-CP11 (?)	280	-	1.43	5.0	21.79	21.07	15.36	6.07	7.14	11.43	6.79	2.50	0.36	0.71
25-245-4-5 (59-63 cm)	NP13-CP11 (top)	280	-	-	2.86	31.79	15.71	16.79	6.43	6.79	8.93	8.21	1.79	-	0.36
44-390A-5-3 (103-109 cm)	NP13-CP11	430	0.47	-	1.63	42.09	17.21	10.93	5.35	7.21	8.14	3.49	1.86	0.23	-
44-390A-6-6 (118-123 cm)	NP13-CP11	279	-	1.79	6.81	39.78	13.26	11.83	8.24	4.66	7.17	4.66	1.08	0.72	-
25-245-5-4 (105-109 cm)	NP13-CP11	280	-	-	2.14	27.50	16.79	19.29	12.14	3.93	3.21	3.21	5.71	3.57	1.07
25-245-6-1 (114-118 cm)	NP13-CP11	280	-	0.36	2.50	25.0	18.93	17.86	16.43	4.64	2.14	1.79	5.71	2.50	0.71
22-213-15-3 (136-140 cm)	NP12-CP10	317	11.67	0.32	5.99	25.89	23.11	5.68	8.85	5.36	5.68	3.15	2.52	-	1.89
44-390A-7-3 (120-126 cm)	NP12-CP10	466	0.21	0.43	4.72	26.18	14.59	8.80	8.58	13.09	10.52	6.22	3.0	1.93	0.86
44-390A-7-CC (10-15 cm)	NP12-CP10	234	-	-	0.43	9.83	17.95	13.25	3.42	4.70	5.13	14.96	11.54	13.68	3.85
25-245-7-2 (19-23 cm)	NP12-CP10 (base)	274	-	-	0.73	5.47	11.31	10.58	7.66	8.79	12.04	12.04	7.66	11.68	7.66
25-245-8-1 (134-138 cm)	NP11-CP9b	276	-	-	-	-	7.61	16.67	18.48	7.61	4.71	2.90	4.71	7.25	9.06
22-213-16-2 (72-76 cm)	NP9-CP8b	280	-	1.07	6.43	13.21	2.50	7.14	8.93	3.93	0.36	0.71	1.43	2.14	5.36
22-213-16-4 (14-18 cm)	NP9-CP8b	420	-	-	2.38	7.62	5.95	9.29	7.86	4.76	2.62	0.95	1.43	3.33	2.86
25-245-9-2 (117-121 cm)	NP9-CP8a	156	-	-	-	0.64	1.28	-	-	1.92	8.33	17.95	11.54	8.97	2.56
22-216-21-1 (125-130 cm)	NP7-CP6 (top)	280	-	-	-	0.36	1.07	3.57	8.57	13.21	25.0	25.71	13.21	7.14	1.07
25-245-10-1 (30-34 cm)	NP7-CP6	280	-	-	-	0.71	1.07	0.71	3.21	12.86	12.14	21.79	18.21	16.43	7.50
44-390A-8-1 (129-135 cm)	NP7-CP6	155	-	-	-	-	0.65	1.29	3.87	10.32	17.42	25.81	19.35	12.26	5.16

RAY NUMBER (CONTINUED) → / TOTAL ASTEROLITH NUMBER ↓		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
33-317B-42-3 (110-111 cm)	280	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44-390A-4-CC	280	-	-	-	1.08	0.36	-	0.36	0.36	-	-	-	-	-	-	-	-	-	-	-
25-245A-7-2 (136-140 cm)	280	-	0.36	-	-	0.36	-	0.36	0.36	0.36	-	-	-	-	-	-	-	-	-	-
23-219-25-1 (125-130 cm)	280	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25-245-4-5 (59-63 cm)	280	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44-390A-5-3 (103-109 cm)	150	-	0.70	-	0.47	-	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-
44-390A-6-6 (118-123 cm)	279	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25-245-5-4 (105-109 cm)	280	1.07	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25-245-6-1 (114-118 cm)	280	0.36	0.36	-	0.36	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22-213-15-3 (136-140 cm)	317	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44-390A-7-3 (120-126 cm)	222	-	-	0.21	0.43	-	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-
44-390A-7-CC (10-15 cm)	234	0.86	0.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25-245-7-2 (19-23 cm)	274	2.19	1.09	0.36	0.36	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-
25-245-8-1 (134-138 cm)	276	7.25	6.88	2.54	1.81	1.09	0.72	0.36	-	0.36	-	-	-	-	-	-	-	-	-	-
22-213-16-2 (72-76 cm)	280	5.36	6.07	7.14	7.86	5.36	5.00	4.29	2.86	1.79	0.36	0.36	-	-	-	-	-	-	-	-
22-213-16-4 (14-18 cm)	280	5.71	8.33	8.81	5.0	8.10	3.10	4.76	2.38	2.38	0.95	0.48	0.24	0.24	0.24	0.24	-	-	-	-
25-245-9-2 (117-121 cm)	156	-	0.64	0.64	-	-	0.64	-	2.56	1.28	3.21	4.49	5.77	9.62	4.49	2.56	3.85	2.56	1.92	0.64
													(+ 35 rays: 1.92%)							
22-216-21-1 (125-130 cm)	280	0.71	-	-	-	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-
25-245-10-1 (30-34 cm)	280	5.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44-390A-8-1 (129-135 cm)	155	1.94	1.29	-	0.65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

ray number as more significant than the outline: species were mainly defined according to the ray number, and only varieties were based upon outline variations. BRAMLETTE and RIEDEL (1954) revised the *Discoaster* taxonomy and proposed the opposite, ranking the ray number lower than the outline (AUBRY, 1984). The modern *Discoaster* taxonomy has been principally developed according to the latter scheme (the ray number is used in the definition of a few species only). An attempt is made here to test the former scheme, which should yield more consistent results in poorly preserved assemblages, because the ray number can be easily evaluated even for diagenetically altered asteroliths.

TECHNICAL METHODS

Conventional smear slides from raw sediment, mounted with Canada balsam, have been investigated with an optical microscope (Table 1). The ray number is recorded for each asterolith encountered along a traverse of the slide, irrespective of its taxonomic position (see procedure in JANIN, 1988, 1989). Counts of 250 to 300 individuals per sample are usually sufficient for accurate evaluation of the discoaster ray number pattern. But for the Oligo-Miocene sediments, where the 6-rayed specimens represent more than 90% of the discoaster population, counts of 1000 to 2000 specimens were needed to obtain a correct evaluation of the abundance of the other asterolith types. Because the various morphotypes are unevenly distributed in the assemblages (JANIN, 1988), two traverses located at the opposite sides of the same slide were generally analysed of each sample. The resulting difference between the two counts did not exceed 3 to 5%. For a few samples containing discoaster-poor assemblages, counts of up to 10 traverses were necessary.

Uncertainties on the ray number only appear for asteroliths with many arms (the possible error does not exceed 1 ray for morphotypes with 12-18 rays, 2 for ones with 19-25 rays, and 3 to 5 for ones with more than 25 rays, especially *D. megastypus*), or for some 3-rayed specimens corresponding either to individuals originally composed of 3 rays, or to 6-rayed ones partly dissolved due to diagenetical processes (JANIN, 1987). The abundance of each morphotype is determined by its percentage with respect to the total number of asteroliths analysed in the slide. This procedure eliminates the drawbacks of the quantitative methods based on indirect determination of species abundance in the sediment, such as that described by BACKMAN and SHACKLETON (1983): see critical review by WEI (1988). The method is also more precise and objective than the semiquantitative procedure in general use (number of specimens per fields of view: see for instance the DSDP Reports), and than the discoaster quantification proposed by DRIEVER (1981, 1984, 1988) for Pliocene assemblages,

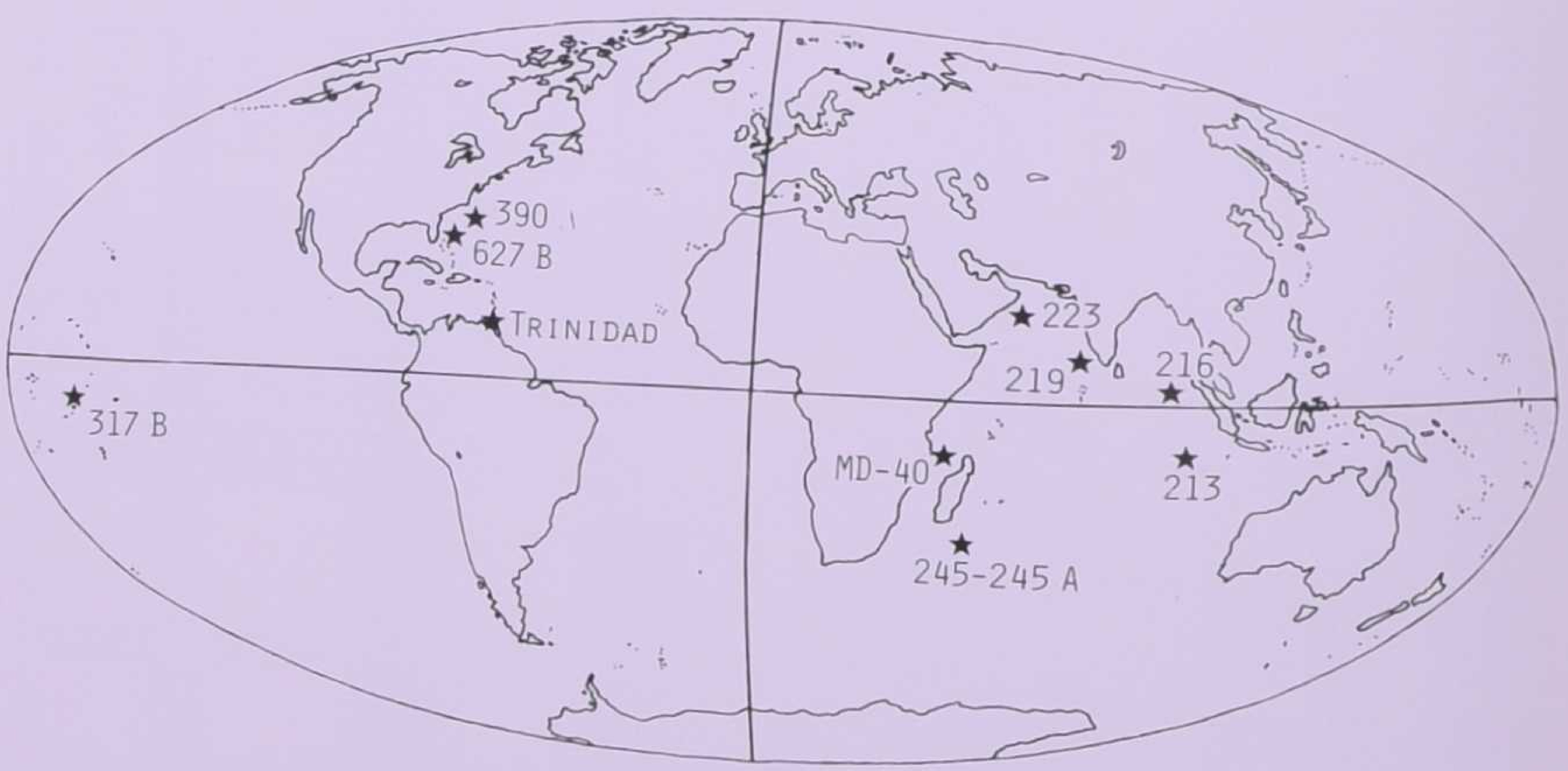

FIG. 2a

FIG. 2a, b - Geographical (Fig. 2a) and stratigraphical (Fig. 2b) location of the studied samples. Numerical ages according to ODIN (1982, 1989), and calcareous nannofossil biozonation according to MARTINI (1971: NP/NN) and BUKRY (1981b: CP/CN). Stars: samples devoid of discoaster; squares: samples of which the age assignment is questionable.

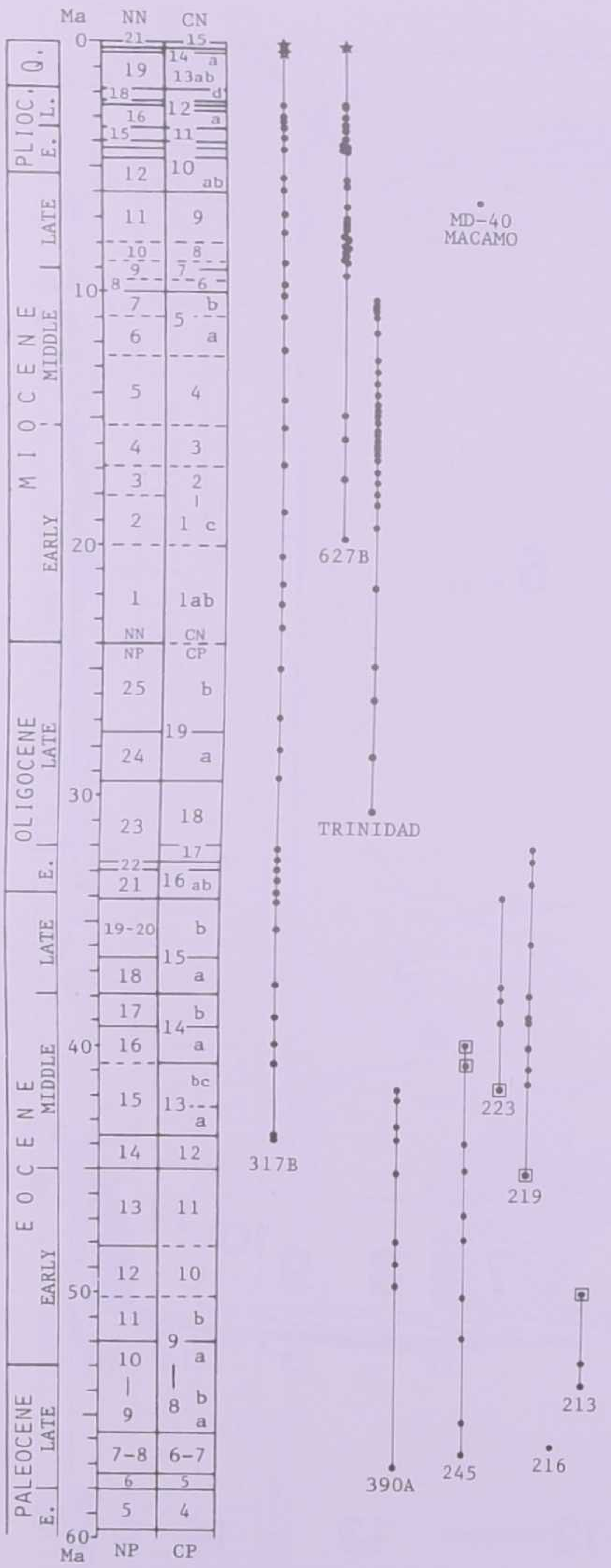

FIG. 2b

where unquantified (and thus sometimes ambiguous) morphological features are taken into consideration apart from the objectively defined ray number.

Another advantage of the method is to minimize the drawbacks due to reworking. Since the ray numbers vary from one biozone to another, and since no morphological feature can be used to detect the reworked nannofossils, the mixing of non-contemporaneous populations may influence the ray number pattern of the discoaster population. But the error is minimized by the fact that the reworked specimens rarely exceed a limited percentage of the total population.

AGE AND LOCATION OF THE SAMPLES STUDIED

147 samples (see Table 1 and Appendix) were selected from sections already thoroughly investigated by other authors using conventional stratigraphical methods: Trinidad type localities, and Atlantic, Pacific and Indian Ocean DSDP/ODP sites (Fig. 2a). An isolated sample from the Mozambique Channel (MD40-MACAMO-DR03) was also analysed for comparison. With the 148 samples analysed, most of the biozones of MARTINI (1971) or BUKRY (1981b) are covered by at least two samples from different oceans (Fig. 2b). Site location and references of previous investigations are given in the Appendix. The age assignment of each sample, according to the MARTINI's and BUKRY's biozonations, is indicated in Table 1.

The numerical time scale used in the figures is based principally on the radiometric age estimates of main stage boundaries, as summarized in ODIN (1982, 1989). The major discrepancy between this time scale and others (see for instance HAQ *et al.*, 1987) is the location of the Eocene/Oligocene boundary (= top of the Priabonian stage). Recent decision of the redefinition of the Eocene/Oligocene boundary recommends the section in Massignano (Apennines: ODIN and MONTANARI, 1988). This section, and several correlative sections in the area, were directly radiometrically dated (ODIN, 1989). The accuracy of these new dates supersedes previous data, and the Eocene/Oligocene boundary age is now accepted at 33.7 ± 0.5 Ma. It corroborates ODIN's (1982) view, locating this boundary near 34 Ma (see also SWISHER and PROTHERO, 1990). Consequently, I adopted in the present paper a time scale consistent with this datation, which is constructed as follows:

1) The calcareous nannofossil biozonal boundaries are correlated with the magnetic polarity scale according to the most recent data available:

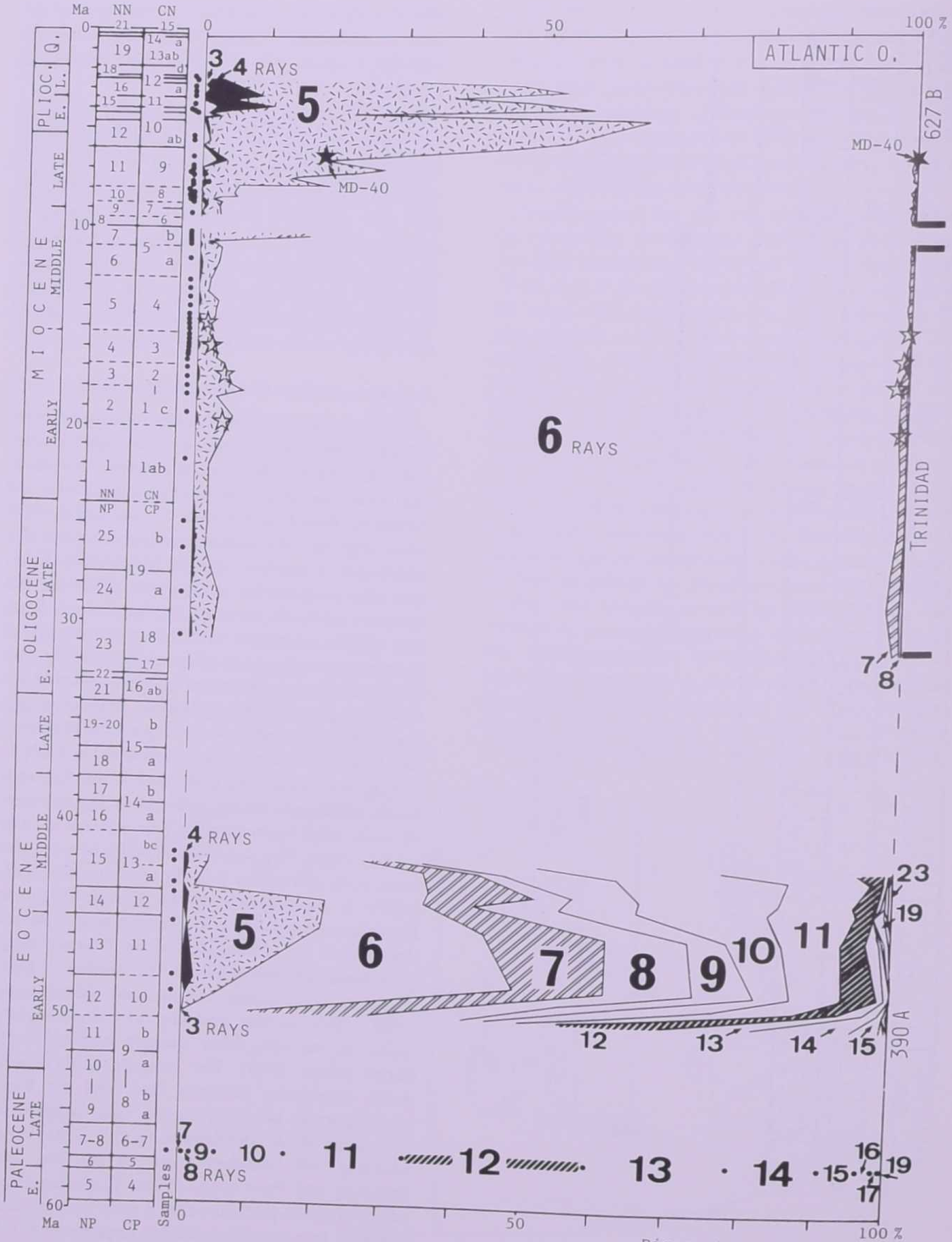

FIG. 3 - Discoaster ray number variation in the Atlantic ocean, as obtained at the DSDP site 390A (Paleocene-Eocene), at Trinidad (Oligocene-middle Miocene) and at the ODP site 627B (late Miocene-Pliocene, and white stars in the early and middle Miocene). The percentage of asteroliths with each ray number type (from 3 rays to 23 rays) is evaluated with respect to the total number of asteroliths counted in the sample. The late Miocene data from the Indian Ocean (MD-40 MACAMO: black stars) are consistent with that from the Atlantic ocean.

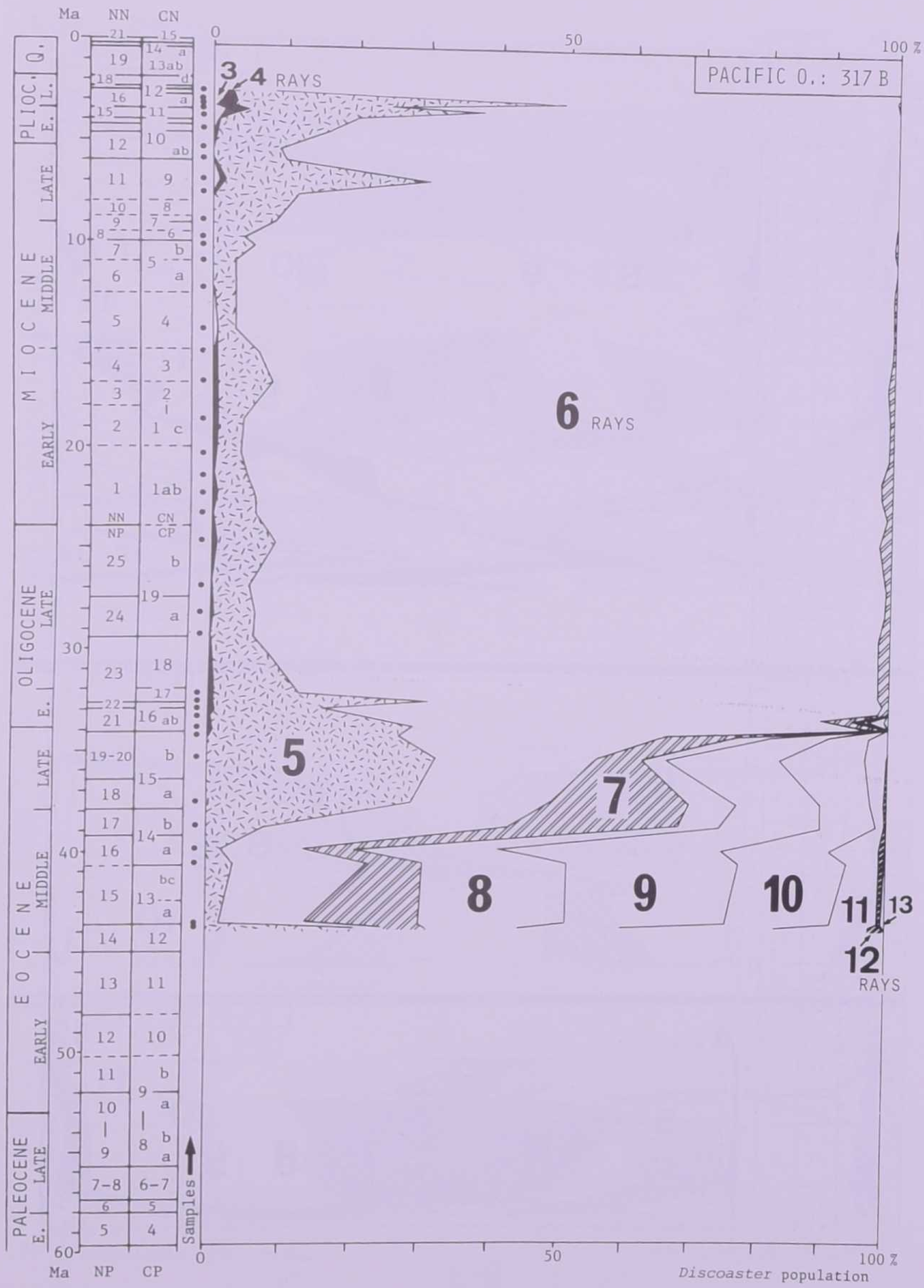

FIG. 4 - Discoaster ray number variation in the central Pacific, site 317B of the DSDP. The evolutionary trends are the same as in Atlantic (Fig. 3) and Indian (Fig. 5a) oceans.

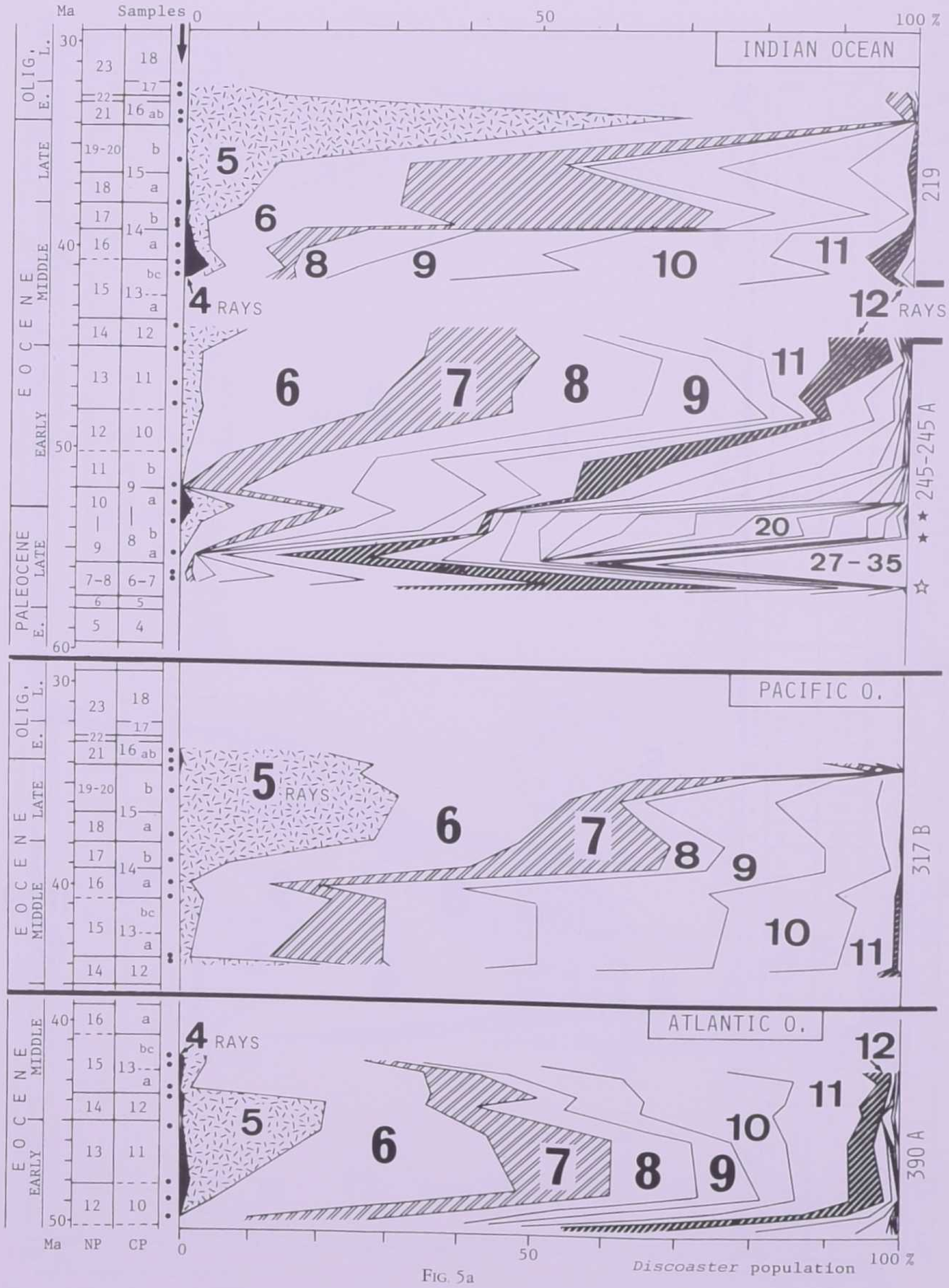

FIG. 5a

FIGS. 5a, b - Discoaster ray number variation in the Paleogene of the Indian Ocean (Fig. 5a, top), and comparison with the evolution in the Pacific (5a, centre) and Atlantic (5a, bottom) oceans. Correlation with the abundance variation of the discoaster species (Fig. 5b), evaluated by the percentage of each taxon with respect of the whole discoaster population.

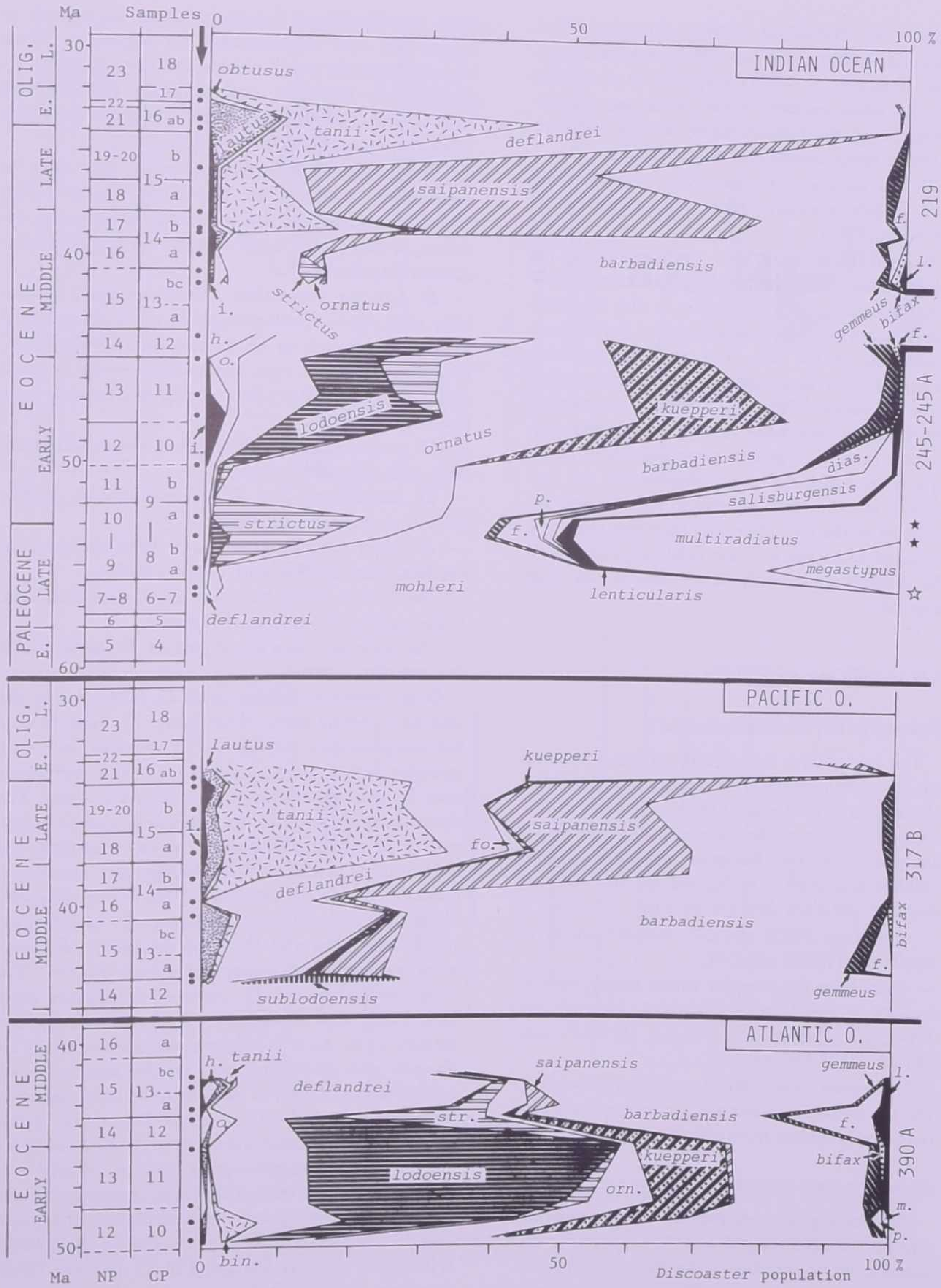

FIG. 5b

FIGS. 5a, b - (*continued*) Black stars: samples from site 213; white star: sample from site 216. *bin.* = *D. binodosus*, *dias.* = *D. diastypus*, *f.* = *D. falcatus*, *fo* = *D. formosus*, *h.* = *D. hillii*, i = unidentified *Discoaster* species, *l.* = *D. lenticularis-wemmelensis*, *m.* = *D. multiradiatus*, *o.* = *D. obtusus*, *or.* = *D. ornatus*, *p.* = *D. pacificus*, *str.* = *D. strictus*.

HILLS and THIERSTEIN (1989) for the Plio-Pleistocene, WEI and WISE (1989a) for the Paleogene, POORE *et al.* (1983) and HAQ *et al.* (1987) for the other periods (these latter age assignments being more questionable because they are based on fewer nannofossil observations).

2) The polarity chronozones are correlated with ODIN's numerical time scale according to CHANNEL (1982).

For the DSDP/ODP sites, the samples are located within the corresponding nannofossil biozones according to their depth in the sequence with respect to the probable depth of the biozone boundaries at the site. For this interpolation procedure it is assumed that the sedimentation rate is constant within a biozone, assumption which seems reasonable for the sedimentary sequences involved. The other samples, from intervals from which sediment thicknesses are unknown, are arbitrarily located in the age interval assigned to the corresponding biozones (they are arranged according to their relative positions in the sections, and evenly distributed in the time interval).

ANALYTICAL RESULTS

DISCOASTER RAY NUMBER VARIABILITY

The quantitative data (Table 1) are illustrated for each ocean separately in figures 3 (Atlantic), 4 (Pacific) and 5a (Indian Ocean). In order to increase the clarity of the figures, the single sample analysed from the Neogene of Indian Ocean (MD-40-MACAMO) is figured on the Atlantic diagram, and a few data are omitted:

— those from DSDP site 223, that are similar to results from DSDP site 219;

— those from the samples whose stratigraphical location is questionable (213-15-3, 136-140 cm; 219-25-1, 125-130 cm; 245-3-4, 119-123 cm; 245A-6-3, 132-136 cm).

The results show a striking similarity between the ray number variations in contemporary discoaster populations from different regions.

PALEOCENE-EOCENE MORPHOTYPE ANALYSIS

The fairly good preservation of the Paleocene and Eocene assemblages, and the importance attached to the ray number in the Paleogene discoaster taxonomy, made it possible to assign a species name to nearly all of the Paleocene-Eocene asteroliths during the process of ray number counting. The percentage of unnamed asteroliths never exceeded 3% of the analysed discoasters. The results are illustrated for each ocean separately in figure 5b, and summarized in figure 6. Some morphologically similar taxa are here lumped together (see LOEBLICH and TAPPAN (1966-1973), VAN HECK (1979-1982) and STEINMETZ (1983-1989) for full taxonomic references):

— *D. mohleri* and *D. barbadiensis*, that may be sometimes confused in the early Eocene (the transition is marked by a drastic abundance decrease of the group with respect to the total discoaster population);

— *D. falcatus* and other rosette-shaped asteroliths with more developed arms than *D. mohleri-barbadiensis*, such as *D. helianthus*, *D. limbatus*, *D. splendidus*, ... (see discussion in BRAMLETTE and SULLIVAN (1961); this group is probably very heterogeneous);

— *D. gemmeus* and all the rosette-shaped asteroliths with truncated arms;

— *D. lenticularis* and *D. wemmelensis*, closely related as indicated by PRINS (1971);

— *D. bifax* and *D. praebifax*, differentiated for the first time by WEI and WISE (1989b);

— the various morphotypes of *D. multiradiatus: pedunculatus, perpolitus, robustus*, ...;

— the different morphotypes of *D. tanii* (*nodifer, ornatus, tanii*).

D. cf. *formosus* differs from *D. formosus* by the lack of a central knob. The name *D. hillii* is used for morphotypes similar to *D. ornatus*, but with straight rather than curved rays; the difference may be due to intraspecific variation only. The distinction between *D. barbadiensis* and *D. saipanensis* is essentially based on ray number, the morphology of the ray tips being very similar, as mentioned by THEODORIDIS (1984). The discrimination between *D. multiradiatus, D. salisburgensis, D. diastypus* and *D. bifax-praebifax*, is somewhat subjective in many cases (see below). The morphotype named *D. strictus* comprises large asteroliths with straight, conical and more or less slender rays. As it is often associated with *D. lodoensis* and more common in the less well preserved assemblages, it may partly correspond to overgrown *D. lodoensis*. Apart from rare typical specimens with bifurcated rays, *D. deflandrei* includes various morphotypes with 6 (rarely 5 or 7-8) massive but well developed rays, that possibly represent overgrown individuals of other species (MARTINI, 1976; JANIN, 1987). Specimens with short rays are assigned to *D. obtusus* (truncated ray tips) or *D. lautus* (pointed ray tips). As for *D. gemmeus*, these units seem to be partly constituted of worn or overgrown specimens from various taxa (JANIN, 1987). No attempt was made to separate taxa in the late Oligocene and

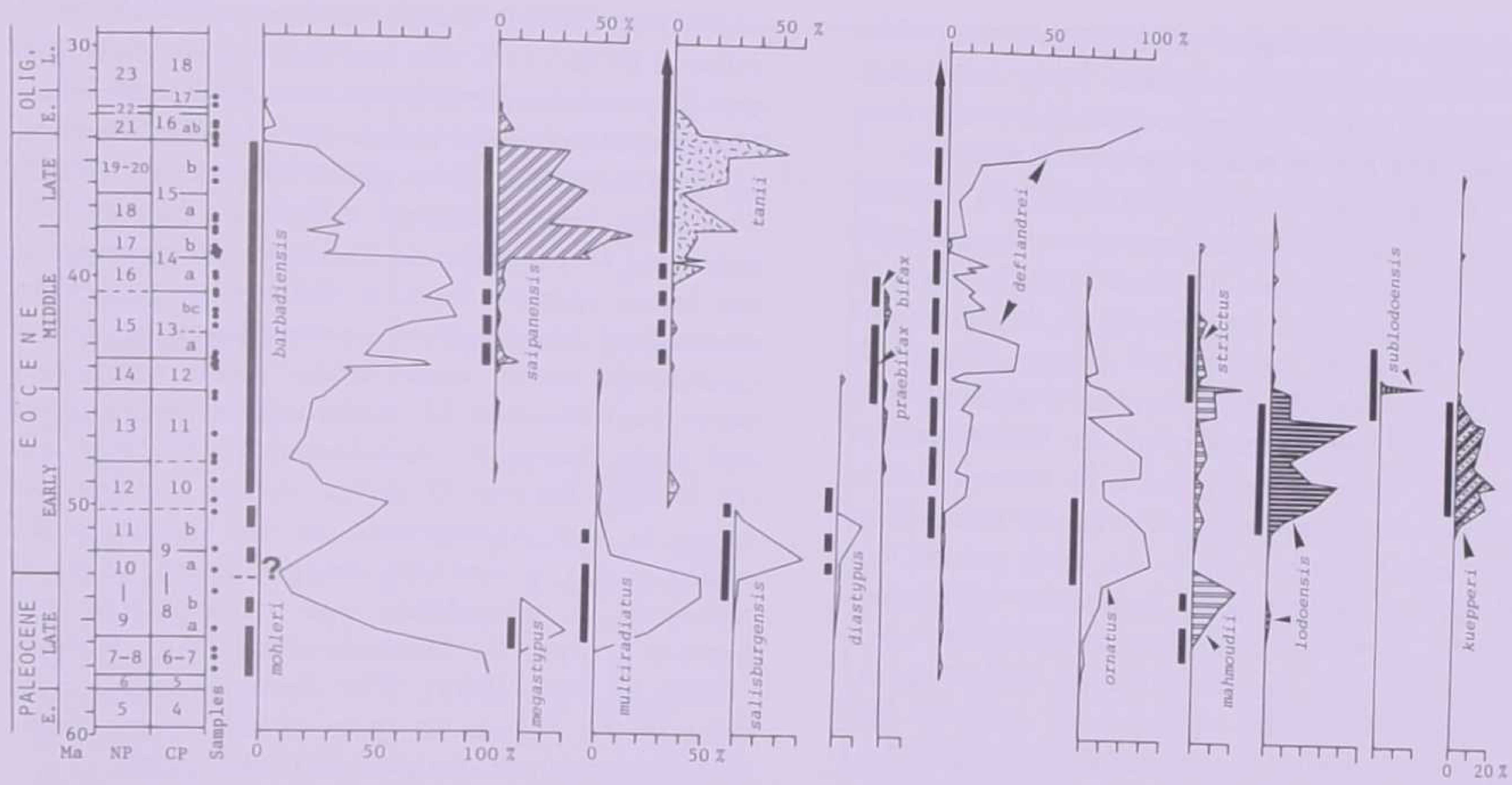

FIG. 6a

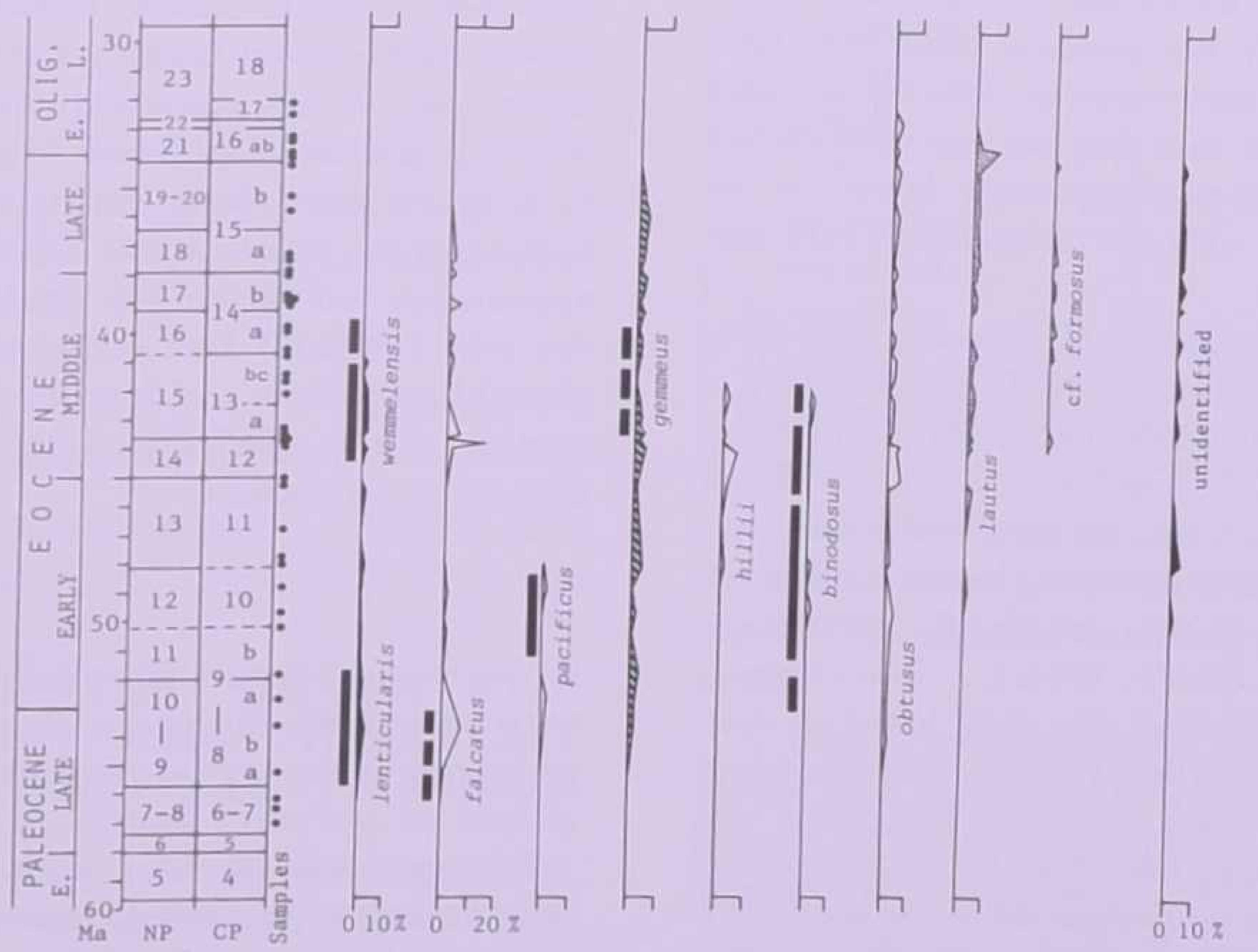

FIG. 6b

FIGS. 6a, b - Synthesis showing the abundance variation of the Paleogene species identified in all the samples investigated. The abundance is represented by the percentage of each species with respect to all the asteroliths counted in the sample. The theoretical extension of the ranges given on the left side are from PERCH-NIELSEN (1985), with addition of a few data from ROMEIN (1979) and WEI and WISE (1989b).

Neogene assemblages, where most asteroliths have 5 or 6 rays, and where many taxonomic criteria consist of subtle morphological variations sometimes not obvious in the studied material.

Owing to the broad species definition adopted here for the Paleogene discoasters (especially *D. falcatus, D. gemmeus, D. lautus* and *D. obtusus*), the stratigraphical distribution of the taxa indicated by all the investigated samples (Fig. 6) is consistent with the range known from the literature: see data compilation in PERCH-NELSEN (1985). The main exception is *D. ornatus*, which during this study was found to be still common in the middle Eocene from the three oceans, although it has not been mentioned by ROMEIN (1979) above the early Eocene. Different taxonomic concepts may be involved, as well as incomplete knowledge of the total range of this species. *D. ornatus* is not used as a stratigraphical marker, and that may be the reason it escaped the routine examinations.

As noted by BACKMAN (1986) and others, most species still occur in small quantity well above their theoretical "extinction" level. Such specimens are generally interpreted as being reworked, but their regular occurrence in different sections may let us assume that they are survivors rather than contaminations. Appearance levels are in better agreement with the bibliographic data, except in few cases:

— The first occurrence of *D. lodoensis* is an early Eocene datum (MARTINI's NP11/12 boundary = OKADA and BUKRY's CP9/10 boundary). It is here observed in DSDP samples 213-16-4, 14-18 cm and 213-16-2, 72-76 cm, assigned to the latest Paleocene (NP9-CP8b) according to the local evolution of the whole nannofossil assemblage (GARTNER, 1974; BUKRY, 1974a). Two explanations may be proposed: 1) a local hiatus or condensation of the earliest Eocene, with mixing of the assemblages from NP9 and NP12 (the site description (BORCH, CHRISTOPHER, SCLATER *et al.*, 1974) points to a contamination of the late Paleocene sediments of Core Catcher 16 with early Eocene elements); 2) a misinterpretation of the specimens, that are somewhat overgrown (the most diagenetized ones are referred to *D. strictus*) and display some ressemblance with overgrown *D. mahmoudii* (or small *D. okadai?*).

— The first occurrence of *D. sublodoensis* cannot be precisely located here, because *D. sublodoensis* is only distinguishable from 5-rayed morphotypes of *D. lodoensis* in well preserved assemblages.

— The first occurrence of *D. bifax-praebifax* is here recorded below the levels indicated by WEI and WISE (1989b). These authors emended the *D. bifax* of BUKRY (1971b) and created the new species *D. praebifax* in order to accomodate *D. bifax*-like asteroliths found below the *D. bifax* theoretical first occurrence level given by BUKRY (1971b). The main morphological difference between *D. bifax* and *D. praebifax* is a greater ray number in the latter species. Such a distinction cannot be maintained in overgrown assemblages, because a continuum seems exist under such conditions from the Paleocene *D. multiradiatus-megastypus* and early Eocene *D. salisburgensis-diastypus* till the middle Eocene *D. bifax*. A ray number decrease is well documented in the Paleocene *D. multiradiatus*, where this morphological group is common to abundant: see quantitative ray number analysis by MOSHKOVITZ (1967), ROMEIN (1979) or WEI (1989). The decrease seems continue in the Eocene in spite of the drastic abundance reduction of the group (JANIN, 1990).

However, divergences from the stratigraphical distribution mentioned in the literature concern only either a small number of the specimens analysed in each sample (less than 5%), or taxa unprecisely defined, rarely recorded and not involved in the usual biozonal schemes. The main index species are common with regard to the whole discoaster population (they represent 5 to 95% of the asteroliths during their total range). Consequently, most of the difficulties in defining appearance and extinction levels are eliminated if the true first and last occurrence levels are replaced by the first and last levels where the percentage of the species exceeds 5% of the whole discoaster population.

RELATIONSHIP BETWEEN DISCOASTER RAY NUMBER VARIATION AND MORPHOTYPE SUCCESSION

Paleogene ray number variation and morphotype succession are compared in figure 5. The results are similar for the different areas, and consistent with the general evolutionary trends described in the literature (BUKRY, 1971a). With respect to the ray number variability per species (Table 2), the following events are noted:

1) Rapid development of asteroliths with more than 15 rays with the appearance of the *D. multiradiatus-megastypus* group in the late Paleocene. The well known ray number decrease in this group and its transition to *D. salisburgensis, D. diastypus, D. praebifax* and *D. bifax* is reflected by the progressive disappearance of the multi-

TABLE 2 - Ray number of the cited *Discoaster* and *Catinaster* species, according to their original description

TAXA	RAY NUMBER	TAXA	RAY NUMBER
C. calyculus	6	*D. mohleri*	9-16
C. coalitus	6	*D. multiradiatus*	16-35
D. asymmetricus	5	var. *pedunculatus*	20-22
D. barbadiensis	9-13	var. *robustus*	15-18
D. bellus	5	*D. neorectus*	6
D. berggrenii	5	*D. nobilis*	7-13
D. bifax	10-15, typically 14	*D. obtusus*	6
D. binodosus	6-8	*D. okadai*	5 (rarely 4, 6-7)
D. brouweri	6, occasionally 5 (rarely 7?)	*D. ornatus*	6-9
D. deflandrei	6, rarely 5 or 7	*D. pacificus*	11-15
D. diastypus	9-16	*D. pentaradiatus*	5-6
D. druggii	6	*D. perpolitus*	22-30
D. exilis	6, rarely 5	*D. praebifax*	16-27, typically 21
D. falcatus	7-10, commonly 9	*D. prepentaradiatus*	5
D. formosus	6-7, rarely 4-5	*D. quinqueramus*	5
D. gemmeus	8-9	*D. saipanensis*	6-7, rarely 5-8
D. hamatus	5, occasionally 6, rarely 3-4, 7	*D. salisburgensis*	? 12
D. helianthus	13-14	*D. splendidus*	14-15
D. hillii	8	*D. strictus*	6 (4 or 5)
D. kuepperi	8-12	*D. sublodoensis*	5, less commonly 6
D. kugleri	6	*D. surculus*	6, rarely fewer
D. lautus	6	*D. tamalis*	4
D. lenticularis	20-26	*D. tanii*	5-7
D. limbatus	8-11, usually 9	var. *nodifer*	5-7
D. lodoensis	6, occasionally 5, rarely 7	var. *ornatus*	5
D. loeblichii	6	*D. triradiatus*	3
D. mahmoudii	5	*D. variabilis*	5-6, very rarely 3-4
D. megastypus	about 30	*D. wemmelensis*	20-30

rayed asteroliths from the latest Paleocene into the middle Eocene (27-35 rays, then 20-25 and 15-20).

2) Increase of 5-9-rayed asteroliths with development of *D. lodoensis* and *D. kuepperi* in the early Eocene. The end of this period is marked by a peak of 5-rayed specimens, obvious as well in Pacific site 317B where *D. sublodoensis* is recorded, as in other areas where no typical *D. sublodoensis* occurs and where most of the 5-rayed specimens are assigned to the *D. lodoensis-strictus* group. This development of 5-rayed asteroliths seems a more suitable event for the NP13/14 (CP11/12) boundary, than the first occurrence of *D. sublodoensis*, a taxon indistinguishable from *D. lodoensis* in moderately well preserved assemblages.

3) Increase of 8-12-rayed asteroliths with the dominance of *D. barbadiensis* in the middle Eocene.

4) Sudden increase of the 7-rayed asteroliths at the end of the middle Eocene, with the development of *D. saipanensis*, already present but rare earlier.

5) Drastic reduction of the percentage of asteroliths with more than 6 rays at the end of the Eocene, reflecting the disappearance of *D. barbadiensis* and *D. saipanensis*. This period is also characterized by a peak of 5-rayed discoasters, principally connected to the development of *D. tanii*. The peak occurrence of *D. tanii* seems to begin slightly earlier in the Pacific site 317B than in the Indian Ocean. This discrepancy may be explained by uncertainties in the stratigraphic position of the samples within the late Eocene. Further investigations are needed to clarify this point. The end of the peak in 5-rayed discoasters, connected to the decrease of *D. tanii* in the middle Oligocene, is more clearly defined.

6) Dominance of 6-rayed asteroliths until the late Miocene, with the *D. deflandrei* group progressively replaced by the more varied and delicate Neogene morphotypes (*D. variabilis, D. exilis,* and *D. brouweri* groups). Despite the succession of different asterolith assemblages, the ray number variability remains strikingly low during the "middle" Oligocene to middle Miocene interval (NP23-NN7), with more than 90% of the population consisting of 6-rayed specimens for over 20 My.

7) Abrupt increase of 5-rayed discoasters near the end of the middle Miocene, representing the main ray number event in the Neogene. Its exact location and correlation with usual taxa (such as *D. hamatus, D. pentaradiatus, D. quinqueramus, D. berggrenii* or *D. asymmetricus*) need further investigation, because the stratigraphic position of the samples, especially from the DSDP site 627B and Trinidad, is questionable. For the same reason, the significance of the successive Pliocene 5-ray peaks with respect to *Discoaster* species, and their possible world-wide synchronism cannot be demonstrated here. As expected, the presence of *D. tamalis* near the early/late Pliocene boundary is reflected by an increase in 4-rayed asteroliths. Specimens similar to *D. triradiatus* occur in the late Pliocene, but the abundance peak mentioned by BACKMAN and SHACKLETON (1983), BACKMAN and PESTIAUX (1987) or DRIEVER (1988), is not observed here, probably due to the older age of the levels analysed.

Although the ray number variation truly reflects the classical species succession described by various authors, it is noteworthy that only a small number of taxa is really involved. Among the 25 taxa here recorded for the entire Paleogene, only 13 represent a percentage of the discoaster population sufficiently high to influence the ray number. Generally, 3 or 4 taxa provide 90% of the asteroliths, and even in the middle Eocene, where a maximum in diversity occurs, only 6 species dominate the assemblage. For the same Paleocene-early Oligocene interval, PRINS (1971) records 36 species (plus 3 unnamed morphotypes), and PERCH-NIELSEN (1985) mentions 46 taxa commonly applied in stratigraphical works. The total number of taxa described from this period reaches 107 according to the catalogues of LOEBLICH and TAPPAN (1966-1973), VAN HECK (1979-1982) and STEINMETZ (1983-1989). If a small part of the difference in the number of species is explained by the broad taxonomic concept adopted here, most of this deviation may be caused by the scarcity of many species. Consequently, a biostratigraphical scheme based on ray number events only, such as that proposed below, will result in a subdivision different from those defined in the usual manner with presence/absence of often rare index species. For instance, the rare *D. nobilis* and *D. bifax*, used in BUKRY's biozonation, are not taken here into consideration, whereas the development of *D. megastypus* and *D. saipanensis*, or the decrease of *D. tanii*, give suitable ray number events.

TENTATIVE CENOZOIC BIOZONATION BASED ON DISCOASTER RAY NUMBER EVENTS

The consistency of the results justifies a proposal of a Cenozoic biozonation based on discoaster ray number events only. In order to make easier the correlations with the commonly used zonal schemes, the new biozones are named D-CP/CN (= *Discoaster* CP/CN) and numbered according to BUKRY's (1981b) zonal frame. The biozones thus obtained are defined in Table 3. These definitions should be read as in the following example:

D. mohleri zone (D-CP6/8-A) is the interval where less than 5% of the discoasters have more than 26 rays [(rn>26) < 5%], and where more than 95% have less than 20 rays [(rn < 20) > 95%]. This zone is equivalent to the lower part of the BUKRY's CP6-8 interval.

Apart from the discoaster ray number events, Table 3 indicates the corresponding discoaster species events, and their correlation with MARTINI's (1971) and BUKRY's (1981b) biozonations. Precise correlation with the discoaster biozonation of PRINS (1971) is more difficult, due to the absence of definitions of the zones used by PRINS, and due to the somewhat different species concepts of this author. The world-wide validity of most of the ray number events selected is warranted by the fact that they match many of MARTINI's and BUKRY's marker events. However, the use of the limit of 5% to define the presence/absence of a morphotype, instead of its first/last occurrence, may result in some divergences from the conventional biozonations. But reworking and problems of extended survival are thus eliminated.

For the Paleogene, 12 intervals are distinguished, of which 6 correspond to MARTINI's (1971) biozonation, and 10 to one of BUKRY (1981b). The appearance of *D. mohleri* is replaced by that of the genus *Discoaster* as a whole, that is somewhat earlier than the F.A.D. of *D. mohleri* according to PERCH-NIELSEN (1985). *D. nobilis*, a species not regularly recorded in litera-

TABLE 3 - Proposal of a D-CP/CN biozonation based on discoaster ray number variation, and correlation with MARTINI's (1971: NP/NN) and BUKRY's (1981b: CP/CN) biozonations. A = Acme of the cited species. In the definition of the D-CP/CN biozones, the meaning of the expression "(rn=5) < 5%" is: the percentage of 5-rayed asteroliths in the discoaster population is less than 5% (see explanation in text)

MARTINI's and BUKRY's BIOZONATIONS

Epoch	NP/NN	CP/CN	*DISCOASTER* EVENTS
PLEIST.	NN19-21	CN13-15	
			↓ *D. brouweri*
PLIOCENE LATE	18	12d	
			↓ *D. pentaradiatus*
PLIOCENE LATE	17	12c	
			↓ *D. surculus*
PLIOCENE LATE	16	12b	
			↓ *D. tamalis*
PLIOCENE EARLY	16–14	11b-12a	
			A↑ *D. asymmetricus*
PLIOCENE EARLY	14	10d-11a	
			↑ *D. asymmetricus*
MIOCENE LATE	12-13	10abc	
			↓ *D. quinqueramus*
MIOCENE LATE	11	9	
			↑ *D. quinqueramus*, *D. berggrenii*, *D. surculus*
MIOCENE LATE	10	8b	
			↑ *D. neorectus*, *D. loeblichii*
MIOCENE LATE	10	8a	
			↓ *D. hamatus*
MIOCENE LATE / MIDDLE	9	7b	
			↑ *C. calyculus*
MIOCENE MIDDLE	9	7a	
			↑ *D. hamatus*
MIOCENE MIDDLE	8	6	
			↑ *C. coalitus*
MIOCENE MIDDLE	7	5b	
			↑ *D. kugleri*
MIOCENE EARLY	2-6	1c-5a	
			↑ *D. druggii*
MIOCENE EARLY	NN1	CN1ab	
OLIG.	NP23-25	CP17-19	
OLIG.	21-22	16	
			↓ *D. saipanensis*, *D. barbadiensis*
EOCENE LATE	17-20	14b-15	
			↓ *D. bifax*
EOCENE MIDDLE	14-16	14a	
			↑ *D. bifax*
EOCENE MIDDLE	14-16	13	
EOCENE MIDDLE	14-16	12	
			↑ *D. sublodoensis*
EOCENE EARLY	12-13	10-11	
			↑ *D. lodoensis*
EOCENE EARLY	9-11	9	
			↑ *D. diastypus*
PALEOCENE	9-11	8	
			↑ *D. multiradiatus*
PALEOCENE	8–7	7	
			↑ *D. nobilis*
PALEOCENE	8–7	6	
			↑ *D. mohleri*
PALEOCENE	6	5	

DISCOASTER RAY NUMBER D-CP/CN BIOZONATION (present work)

DISCOASTER EVENTS	DEFINITION (rn = ray number)	NUMBER	NAME
	no common *Discoaster*	D-CN 13/15	
A↓ *Discoaster* ssp.			
	(rn=5) < 5%	D-CN12d	*D. brouweri*
↓ *D. pentaradiatus*			
	(rn=5) > 5% and (rn=4) < 5%	D-CN 12bc	*D. pentaradiatus*
↓ *D. tamalis*			
	(rn=4) > 5%	D-CN 11b/12a	*D. tamalis*
↑ *D. tamalis*			
↑ *D. quinqueramus*	(rn=4) < 5% and (rn=5) > 10%	D-CN 8/11a	*D. quinqueramus*
?			
↑ *D. bellus*, *D. prepentarad.*	(rn=5) < 10% and (rn>6) < 5%	D-CP17/CN8	*D. deflandrei*
A↓ *D. tanii*			
	(rn=5) > 10% and (rn>6) < 5%	D-CP16	*D. tanii-defland.*
↓ *D. saipanensis*, *D. barbadiensis*			
	(rn>6) > 5% and (rn=5) > 10%	D-CP 12/15-D	*D. tanii*
A↑ *D. tanii*			
	(rn=5) < 10% and (rn<8) > 60%	D-CP 12/15-C	*D. saipanensis*
A↑ *D. saipanensis*			
	(rn<8) < 60% and (rn=5) < 5%	D-CP 12/15 B	*D. barbadiensis*
A↓ *D. sublodoensis* and 5-rayed			
	(rn=5) > 5%	D-CP 12/15-A	*D. sublodoensis*
A↑ *D. lodoensis*			
	(rn=5) < 5% and (rn>14) < 5%	D-CP 10/11	*D. lodoensis*
A↓ *D. diastypus*			
	(rn>14) > 5% and (rn>19) < 5%	D-CP9	*D. diastypus*
A↓ *D. multiradiatus*			
	(rn>19) > 5% and (rn>26) < 5%	D-CP 6/8-C	*D. multiradiatus*
↓ *D. megastypus*			
	(rn>26) > 5%	D-CP 6/8-B	*D. megastypus*
↑ *D. megastypus*			
	(rn>26) < 5% and (rn<20) > 95%	D-CP 6/8-A	*D. mohleri*
↑ *Discoaster* genus			
	no *Discoaster*		

ture (MÜLLER, 1974; WEI and WISE, 1989a) and not found in the present material, is not used. The appearance of *D. megastypus* (rn > 26) seems a better datum for the middle late Paleocene. Due to the lack of samples, the first occurrence of *D. multiradiatus* and *D. megastypus* cannot be separated here. Further investigation will probably result in a subdivision of the D-CP6/8-B interval in two parts on the basis of the first appearance of *D. multiradiatus*. The next three following events emanated from the *D. multiradiatus-salisburgensis-diastypus* succession. Two of these have been selected in such a way that they correlate with the usual biozonations, but the rapid ray number decrease during the latest Paleocene-earliest Eocene offers much scope for a further refinement (WEI and WISE, 1989a). The abundance decrease of this group in the early Eocene coincides with the development of *D. lodoensis*. The first appearance datum of *D. sublodoensis*, marking the boundary between two successive zones in the standard zonations, is replaced here by the development of 5-rayed asteroliths, an event more easily identified. The end of this 5-ray peak interval, that is accompanied with the decrease in abundance of the *D. lodoensis* group, seems to be a more reliable middle Eocene event than the usual ones, which are traditionally based on the sporadic *Rhabdosphaera gladius, R. inflata* and *Chiasmolithus gigas*, or on the rare *D. bifax*. The development of *D. saipanensis* is also a well defined event near the middle/late Eocene boundary, as suggested by MÜLLER (1974). The increase and decrease of 5-rayed asteroliths (*D. tanii*) below and above the disappearance of the rosette-shaped discoasters represent two supplementary events in the late Eocene and early Oligocene, where reliable markers are rare (BARBIN, 1989 and references therein).

For the Neogene, only 6 intervals have been defined in the present work, because the ray number variation is not well understood, except for the 4-ray peak, correlated with the *D. tamalis* occurrence. Although no sample has been analysed above NN17-CN12c, a biozone D-CN12d, characterized by a low percentage of 5-rayed asteroliths, is proposed. It corresponds to the latest common occurrence of the *Discoaster* genus, represented by *D. brouweri* (and its 3-rayed variety *D. triradiatus*) alone (BACKMAN and SHACKLETON, 1983; PERCH-NIELSEN, 1985; BACKMAN and PESTIAUX, 1987; DRIEVER, 1988). Finer Neogene subdivisions will be probably introduced later (for local use at less), using the 5-6-ray oscillations and the probable 3-ray peak at the top of the NN18.

CONCLUSION

The D-CP/CN biozonation proposed in the present paper is not meant to replace other biozonations usually based on first and last appearances of discoaster taxa and many other calcareous nannofossil groups. Althoug it is evident that the use of a single group cannot lead to a highly refined subdivision, it has the major advantage to minimize the stratigraphical problems related to distinct ecological preferences of various nannofossil groups, and to their selective preservation due to diagenesis. Since, apart from the foregoing, the D-CP/CN biozonation can be applied equally well in discoaster-rich as in poor assemblages, it seems particularly suitable for correlating sequences deposited under different paleoenvironmental conditions.

Moreover, as the ray number pattern is a parameter that continuously varies with time, it potentially allows for more accurate age assignment than the conventional zonal schemes. Therefore, it would be especially valuable for the latest Paleocene-earliest Eocene and the late Eocene-earliest Oligocene intervals, where many rapid and irreversible changes occur.

APPENDIX

SAMPLES INVESTIGATED

1) *Trinidad samples*

32 samples (TR1 to TR 32) from a few localities in the Cipero Formation of Trinidad (Fig. 7), have been provided by Dr. G. GLAÇON, who collected them during the field trip H of the 4th Latin American Geological Congress (CHRISTIAN *et al.*, 1979). Most of them come from the type or cotype localities of BOLLI's (1957) planktonic foraminiferal zonation, and their stratigraphic position is thus precisely defined in terms of planktonic Foraminifera. Investigation of the calcareous nannofossil assemblages (Fig. 8) shows approximately the same species distribution as previously described from Trinidad, especially by MARTINI (1971), who also used the Oligo-Miocene Cipero Formation as reference in his biozonation. The main difference is the absence of typical specimens of *Sphenolithus ciperoensis* in the late Oligocene, which may be explained by the scarcity of the sphenoliths (except *S. moriformis*) in the corresponding samples. Abundant discoasters occur in all samples except TR28, that consequently was not included in this study.

2) *DSDP/ODP samples*

With the exception of the samples from the Pacific site 317B, that were directly obtained from the Deep Sea Drilling Project, the DSDP/ODP material has been provided by Drs. C. GUERNET (Paleogene) and E. FOURCADE (Neogene). Rapid scanning of the whole calcareous nannofossil assemblage generally confirmed the age assignments proposed by the first investigators listed in Table 4.

22-216-21-1 (125-130 cm): No true *D. nobilis* occurs in this sample, but some specimens transitional between *D. mohleri* and *D. nobilis*, indicating top CP6, have been observed.

23-219-17-5 (14-18 cm) and 23-223-32-1 (96-100 cm): Precise location within the late Eocene is uncertain, as is usual for low latitude areas (absence of *Isthmolithus recurvus* and taxonomic problems related to *Sphenolithus pseudoradians*: see comments *in* PERCH-NIELSEN, 1985).

BIOZONE MARTINI (1971)	PLANKTONIC FORAMINIFERA ZONES	SAMPLE NUMBER FORAMINIFERA TYPE-LOCALITY	SAMPLE NUMBER OTHER LOCALITY	BIOZONE CALC. NANNOF. PRESENT STUDY
NN 8	*Globorotalia siakensis (mayeri)*	TR 9		
NN 7	*Globorotalia fohsi robusta*			TR 9 = NN 7 (top)
	Globorotalia fohsi lobata		TR 8	TR 8 = NN 7
NN 6	*Globorotalia fohsi fohsi*	TR 26-27	TR 6	TR 6, 26-27 = NN 7
	Globorotalia f. peripheroronda	TR 5		TR 5 = NN 6
	Praeorbulina glomerosa		TR 7, 10-12	TR 4, 7, 10-12, 13
NN 4	*Globigerinatella insueta*	TR 13	TR 4, 24	and 24-25 = NN 5
NN 3	*Globigerinita stainforthi*		TR 1-3	TR 1-3, 20-23 = NN 4
NN 2	*Globigerinita dissimilis*	TR 15		TR 15-17 = NN 3
NN 1	*Globigerinoides primordius*			TR 18-19 = NN 2
	Globorotalia kugleri	TR 14		TR 14 = NN 1
NP 25	*Globigerina cip. ciperoensis*	TR 31		TR 31-32 = NP 25
NP 24	*Globorotalia op. opima*	TR 30		TR 30 = NP 24
NP 23	*Globigerina ampliapertura*	TR 28		TR (28?)-29 = NP 23

FIELD TRIP H GUIDE STOP NUMB.	SAMPLE NUMBER (TR)
Golconda Estate	
6	1
(Old Golconda Railway station)	
	2-4
7	5
	6-7
8	8
9	9
Hill near the old Hermitage Quarry	
10	10-12
Oropuche field	
11	13
Mosquito Creek	
12	14
Cipero Coast	
13	15-19
14	20-23
15	24
16	25
17	26-27
18	28-30
19	31-32

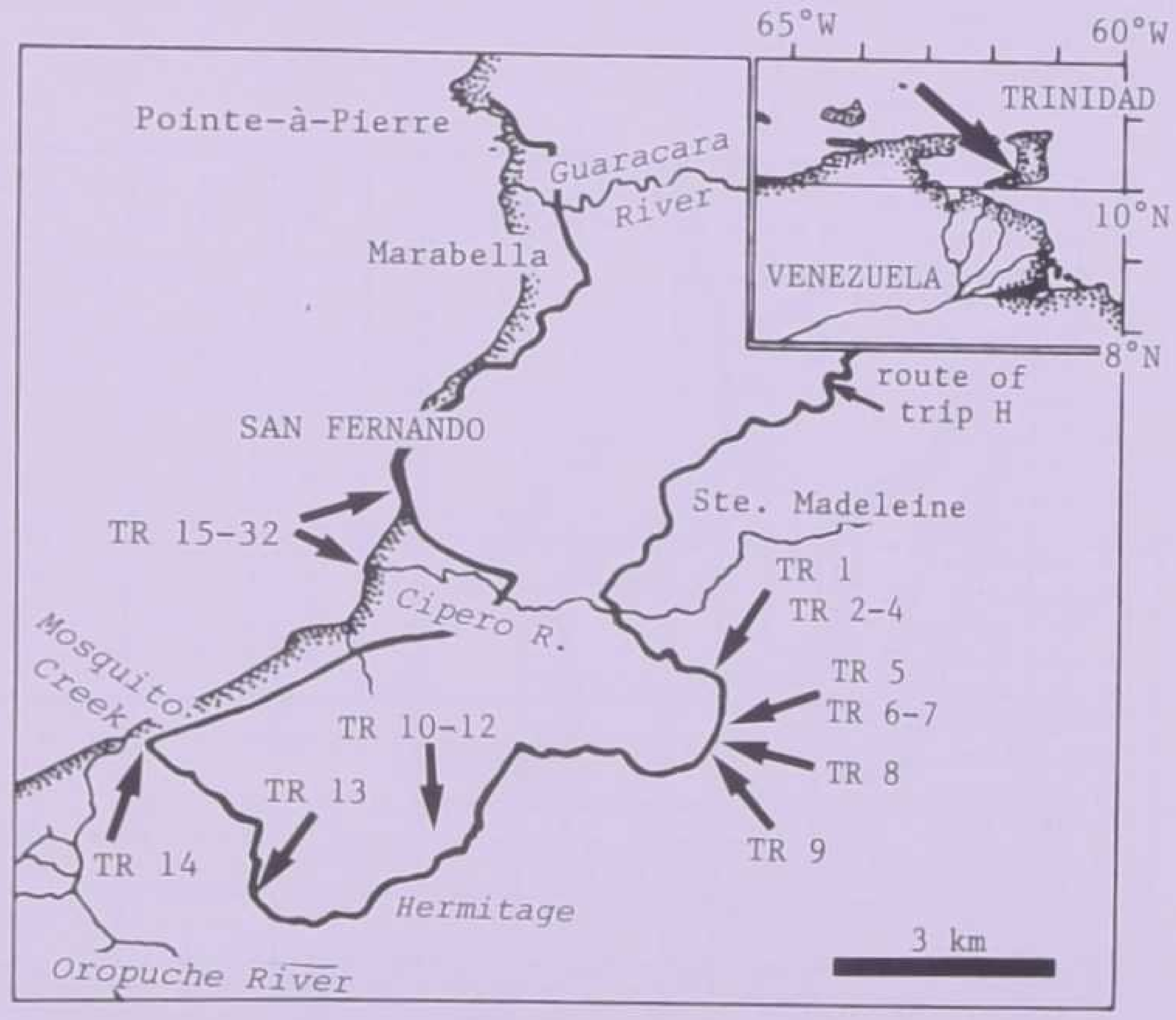

FIG. 7 - Geographical and biostratigraphical location of the Trinidad samples investigated, according to Dr. G. GLAÇON (pers. comm.) and CHRISTIAN *et al.* (1979). Correlation between the biozones of calcareous nannofossils (NP/NN) and of planktonic Foraminifera according to MARTINI (1971).

25-245-10-1 (30-34 cm): The abundance of *D. mohleri* characterizes the upper part of CP6 following BUKRY's (1974c) site description (*D. mohleri* is locally scarce in CP7 and in the lower part of CP6).

101-627B-5H-6 (50-52 cm) to 101-627B-9H-5 (50-52 cm): The age assignment is questionable because of discoaster overgrowth and sporadic occurrence of Ceratolithaceae. It is principally based on the investigation of planktonic Foraminifera by MELILLO (1988).

3) *MD-40 MACAMO sample*

The sample (M-84, DR-03-1′), obtained by the courtesy of Dr. J. HERNANDEZ, consists of a late Miocene calcareous nannofossil and planktonic Foraminifera ooze dredged in the Mozambique Channel (11°S 41°30′E, depth: 2200 m, Fig. 9) during cruise MD40-MACAMO. The sample was taken at the surface of a fragment of "alkaline basalt bearing peridotite nodules" (MOUGENOT *et al.*, 1986, 1989). The well preserved calcareous nannofossil assemblage (Fig. 9) characterizes the upper part of the late Miocene NN11 (= CN9b). This result agrees with the middle Miocene (N14) to Recent (N23) age provided by the planktonic Foraminifera from the various sediments collected by the dredging M84-DR03 (Prof. M. MOULLADE, pers. comm.).

BIOZONES NP/NN	23	?	24	25		1	2		3			4							5								6	7				
SAMPLE NUMBER: TR	29	28	30	31	32	14	19	18	17	16	15	20	1	21	2	22	3	23	4	13	10	11	12	24	7	25	5	26	6	27	8	9
B. rosa		*																														
C. leptoporus												*	R		R	*	*		*	*		*			R		*	*	R	R	*	*
C. macintyrei							*			*		*				*			*			*	*	*	R	R	*	R	R	R	*	*
C. fuscus								*							*																	
C. gr. *pelagicus*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
C. tenuis		*																														
E. subdisticha		*																														
E. femurcentrum		*																														
E. fenestrata	*	*	*																													
Coronocyclus ssp.	*		*			*	*	*	*	*	*			*	*	*	*		*	*	*	*	*	*	*	*	*		*		*	*
Cat. altus																											*					
D. pentaradiatus																											*					*
D. quinqueramus																											*					
D. kugleri																												[*]	*	*	*	
D. signus																								*		*	*					
D. petaliformis																						*	*	*	*							
D. challengeri																				*	*	*	*	*	*	*	*	R	*	*	*	*
D. gr. *brouweri*					R		R		R			*		*			*		R	*	*	*	*	*	*	*	*	*	*	R	*	*
D. bellus													*			*																
D. exilis										*		*			*				*	*	*	*	*	*	*		*	*	*	*		
D. intercalaris									*			*			*	*	*	*		*	*		*	*	*	*	*	*	*	*		
D. variabilis						R	R		*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*
D. trinidadensis							*			*			*			*		*		*				*				*				
D. adamanteus									*				*						*	*		*	*		*	*	*		*	*	*	*
D. obtusus			*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*					*						*		
D. prepentariadatus		*	*						*			*			*				R	*		*									*	
D. aulakos	*							*	*	*						*		*	*		*	*	*		*	*		*	*			
D. lautus	*			*	*	*	*	*	*	*		*			*	*	*		*		*		*	*				*				
D. gr. *deflandrei*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	R	*	*				*	R	*	R	R	R	R	R		
D. gr. *druggii*	*	*	*	*	*	*	*	R	*		*	*	*	*	*			*		*												
D. binodosus			*													*			*			*	*									
D. barbadiensis				*			R																							*		
D. saipanensis		*		*								*							*													
H. carteri					*		*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
H. ampliaperta					*		*	R	R	*	*	*	*	*	*	*	*	*]														
H. reticulata			*																													
H. recta		[*]	*		*]				R				R																			
H. compacta	*	*			*	*					*																					
H. intermedia	*		*		*	*	*	*		*	*															*			*			
O. perplexus	*				*	*	*	*	*	*	*	*	*	*		*	*		*		*	*	*	*	*		*		*	R	*	*
Pontosphaera ssp.				*	*			*			*	*							*	*	*			*								*
P. gr. *amphora*																																*
P. gr. *apsteinii*	*									*			*								*		*	*								
P. gr. *discopora*	*	*	*	*	*	*			*	*		*			*					*	*	*	*		*	*	*	*	*		*	*
? *Gephyrocapsa* sp.										R															R				R	R		
Reticulofen. ssp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
R. bisecta				*	*	[*]																										
R. umbilicus]				*																												
R. floridana		*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*		*							
R. abisecta	*			*	*	*							*			*		*														
Rh. vitrea		*																														
Rh. claviger																															*	
Rh. tenuis	*		*		*	*	*	*	*	*			R	*		R					*	*	*		*	*	*	R	*	R	*	*
S. abies					*				*						*					*			*	*	*							
S. belemnos							[R]	*	*																							
S. moriformis	*	R	*	*	*	*	*	*	R	R	*	*	*	*	*	R	*	*	*	*	R	*	*	*	R	R	R	R	R		*	*
S. heteromorphus	R			R								[*]	*	*	*	*	*	*	*	*	*	*	*	*	*	R]	R	?		?		
S. ciperoensis			[?]																													
S. distentus	[*]	*	*]		R		R																									
S. predistentus	*	*	*																													
Syracosphaera ssp.	*						R		*	*		*		*							*						*	*	*	*		
T. rugosus																														*	*	*
T. gr. *carinatus*	*			*		*	*	*]	R	R	R	*	*		R		*	*									*	R	*			
Thoracosphaera sp.										*											*								*			
holococcoliths																						*										
H. macroporus			*																		*											
Z. bijugatus	*	*	*																													

Martini's index species: [and] - auxiliary marker species: [and] (dashed)

FIG. 8 - Calcareous nannofossil distribution in the Trinidad samples (R = rare species), and corresponding age assignment according to MARTINI (1971).

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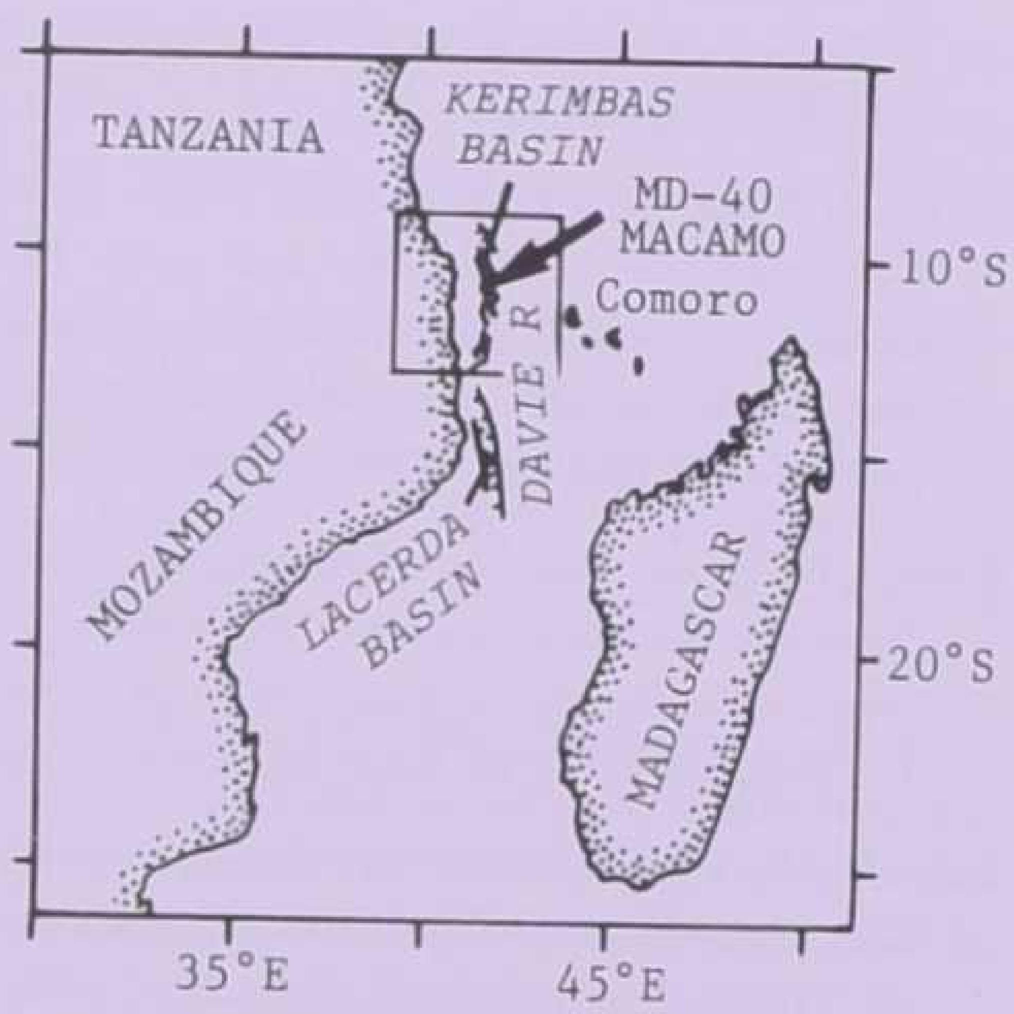
TABLE 4 - References of the main previous investigations concerning the calcareous nannofossils from the DSDP/ODP sites used in the present work

SITE	PREVIOUS NANNOF. INVESTIGATIONS
PACIFIC OCEAN DSDP 317B (Leg 33)	MARTINI (1976)
ATLANTIC OCEAN DSDP 390A (Leg 44) ODP 627B (Leg 101)	BUKRY (1978), SCHMIDT (1978) WATKINS and VERBEEK (1988)
INDIAN OCEAN DSDP 213, 216 (Leg 22) DSDP 219, 223 (Leg 23) DSDP 245-245A (Leg 25)	BUKRY (1974a), GARTNER (1974) BOUDREAUX (1974), BUKRY (1974b) BUKRY (1974c), MÜLLER (1974)

R = rare F = few C = common A = abundant	NN 11 CN 9 a	 b	M84-DR3	NN 12 CN 10 a	 b
INDEX SPECIES					
A. primus		*	R	*	*
D. berggrenii	*	*	F	*	*
D. quinqueramus	*	*	A		
D. surculus	*	*	C	*	*
R. pseudoumbilicus		*	F	*	*
OTHER SPECIES					
A. delicatus			R		
C. leptoporus			F		
C. macintyrei			C		
C. gr. *pelagicus*			C		
D. adamanteus			F		
D. brouweri			C		
D. calcaris			F		
D. lautus			F		
D. neorectus			F		
D. pentaradiatus			C		
D. variabilis			C		
H. carteri			C		
H. sellii			F		
N. coccolithomorpha			R		
P. gr. *amphora*			R		
P. gr. *apsteinii*			R		
P. gr. *discopora*			R		
Reticulofenestra ssp.			A		
Rhabdosphaera stem			F		
R. procera			R		
S. abies			C		
S. neoabies			C		
S. moriformis			A		
T. rugosus			R		
T. striatus			R		



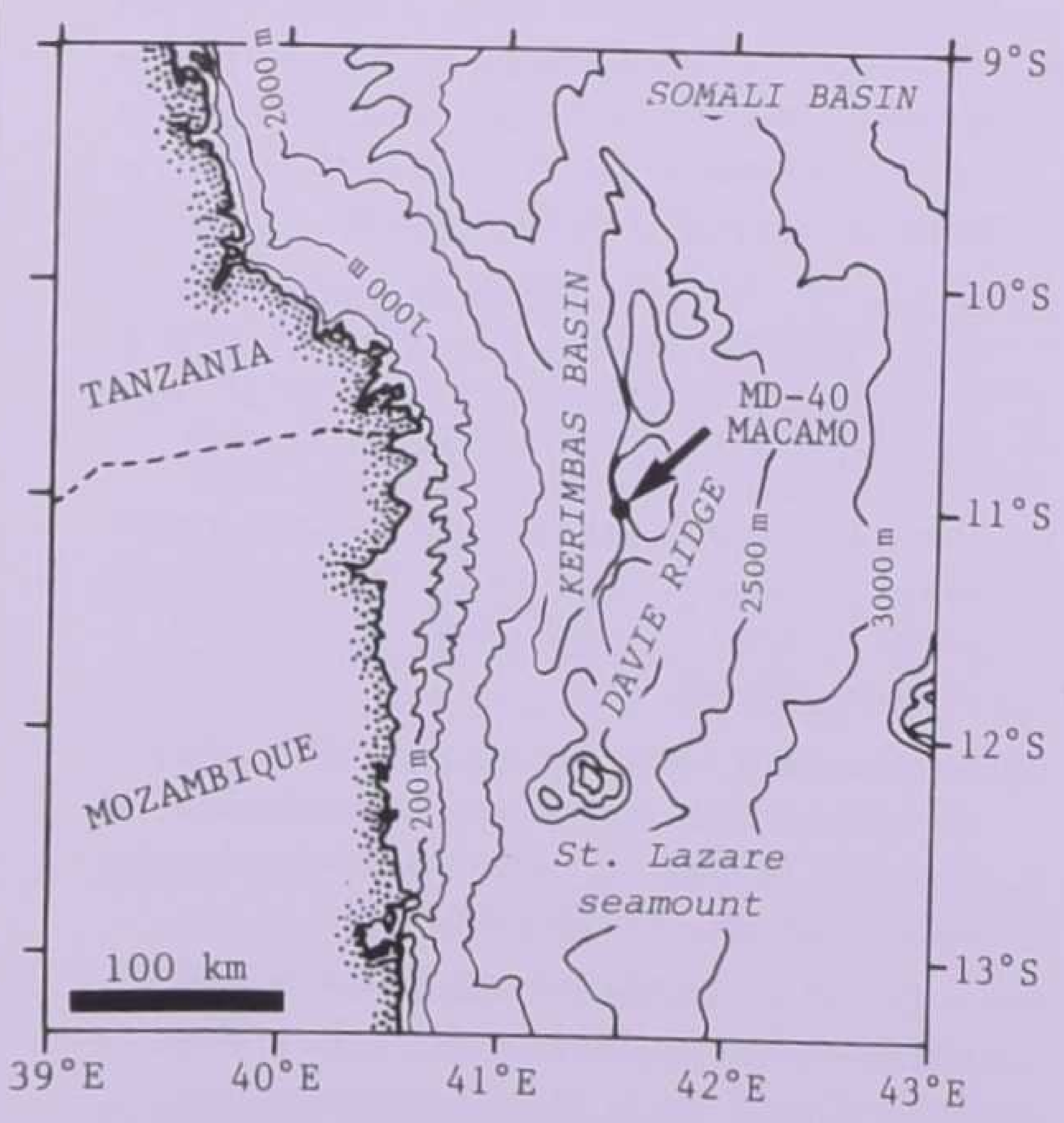


FIG. 9 - Geographical and biostratigraphical location of the sample MD-40 MACAMO from the Mozambique Channel. Map according to MOUGENOT *et al.* (1986).

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MARIE-CHRISTINE JANIN *

THE DISCOASTER RAY NUMBER EVOLUTION: STRATIGRAPHICAL APPLICATION

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Key words: Calcareous nannofossils, Discoaster, *ray number, quantitative data, Cenozoic, Atlantic, Pacific, Indian Ocean, stratigraphy, biozonation.*

ABSTRACT

The stratigraphical value of the star-shaped calcareous nannofossil genus *Discoaster* is well known: according to the usual biozonations, 17 to 25 stratigraphic intervals can be distinguished in the Cenozoic on the basis of discoaster events. However, the application of these zonations can become limited when critical marker species occur in low abundances, or when the assemblages are too poorly preserved to allow precise taxonomic identification of the asteroliths. In order to avoid these difficulties, a quantitative stratigraphical method is proposed based upon the variations of discoaster ray number with time. This method takes into account all specimens, whatever their state of preservation.

Quantitative analyses have been carried out on oceanic calcareous oozes from different areas: Central Pacific (DSDP site 317B), Indian Ocean (DSDP sites 213, 216, 219, 223 and 245-245A; MD-40-MACAMO dredging site DR-03), northwestern Atlantic (DSDP site 390A, ODP site 627B) and Trinidad. The 148 samples selected are representative of the main successive discoaster assemblages known from the first to the last occurrence of the group (middle Paleocene-latest Pliocene). For the Paleocene and Eocene samples, where the assemblages are sufficiently well preserved for precise taxonomic identification of each asterolith, the ray number patterns are compared with the occurring discoaster species.

The results thus obtained are similar in the different regions investigated, and consistent with the general discoaster evolutionary trends described in the literature. They indicate that, among the numerous species validly published, only a few are sufficiently abundant to really influence the ray number pattern of the discoaster population. A Cenozoic biozonal scheme is proposed, comprising 17 biozones exclusively based on variation in discoaster ray number pattern. The zonal units are named according to a number system (D-CP/CN) translated from the Bukry's one. The new zonation has the advantage of using a single and common nannofossil group, without necessity of a refined taxonomy. It seems thus particularly suitable for correlations between sequences deposited under different paleoenvironmental conditions, or for sediments yielding poorly preserved nannofossil assemblages.

* Univ. P.-et-M. Curie (Paris VI), Dépt. Géologie sédimentaire et CNRS URA 1315, 4 Place Jussieu (Tour 15, Étage 4), F - 75 252, PARIS Cedex 05 (France).