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BIOMETRIC STUDY OF *DISCOASTER MULTIRADIATUS* AND ITS BIOCHRONOLOGICAL UTILITY

CONTENTS

Key words: *calcareous nannofossil, Discoaster multiradiatus, biometrics, biochronology, late Paleocene, early Eocene.*

ABSTRACT

Analyses of samples from DSDP Sites 245 (Indian Ocean), 361, 524, 528 (South Atlantic), 577 (North Pacific), and 605 (North Atlantic) show that there is a consistent trend of decrease in the mean ray number of *Discoaster multiradiatus* through time. The mean ray number of *D. multiradiatus* decreases progressively from about 30 near its first occurrence level (base of Zone CP8) to about 17 near its last occurrence level (Zone CP9). Calibration with the magnetostratigraphies in Sites 524, 528 and 577 indicates a relatively consistent mean ray number versus age relationship, especially for the interval of 57.7-58.7 Ma. This indicates that the decrease in the mean ray number of *D. multiradiatus* is virtually synchronous in different oceans. This relationship between mean ray number of *D. multiradiatus* and age enables a considerably higher biostratigraphic resolution than ordinary biostratigraphic methods can achieve for the latest Paleocene-earliest Eocene interval. No clear trend of size change through time was found for *D. multiradiatus*.

RIASSUNTO

Le analisi di campioni dei Sites DSDP 245 (Oceano Indiano), 361, 524, 528 (Atlantico meridionale), 577 (Pacifico settentrionale) e 605 (Atlantico settentrionale) hanno rivelato un consistente *trend* di diminuzione nel tempo nella media del numero di raggi di *Discoaster multiradiatus*. Il numero medio di raggi di *D. multiradiatus* decresce progressivamente da circa 30 in prossimità del livello della sua prima comparsa (base della Zona CP8) fino a circa 17 verso il livello di estinzione (Zona CP9). Nei Sites 524, 528 e 577 la taratura magnetostratigrafica rivela un rapporto relativamente consistente fra la media del numero di raggi e l'età, specialmente per l'intervallo 57.7 - 58.7 Ma. Ciò significa che la diminuzione del numero medio dei raggi di

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D. multiradiatus è praticamente sincrona nei diversi oceani. Il rapporto tra il numero medio di raggi e l'età consente di raggiungere una risoluzione biostratigrafica considerevolmente più alta che con gli usuali metodi biostratigrafici, almeno per l'intervallo Paleocene terminale - Eocene basale. Non è stato rilevato alcun *trend* di cambiamento di dimensioni per *D. multiradiatus*.

INTRODUCTION

Discoaster multiradiatus is of special interest for several reasons: (1) The species was described in the first paper that discussed the biostratigraphic value of calcareous nannofossils (BRAMLETTE and RIEDEL, 1954). (2) *Discoaster multiradiatus* is one of the several calcareous nannofossil stratigraphic markers used in the first nannofossil zonation (BRÖNNIMANN and STRADNER, 1960), and is one of the few nannofossil markers to find application in almost all of the nannofossil zonation schemes proposed for the upper Paleocene (BRAMLETTE and SULLIVAN, 1961; HAY and MOHLER, 1967; EDWARDS, 1971; MARTINI, 1971; BUKRY, 1973; OKADA and BUKRY, 1980; and others). The wide application of this species as a stratigraphic marker is due to its cosmopolitan nature. The species is commonly present in virtually all the upper Paleocene oceanic carbonate sediments recovered from low to high latitudes. Currently available biomagnetostratigraphic correlation data from the mid latitudes to 65°S latitude show that the first occurrence (FO) of *D. multiradiatus* has a relatively consistent age of about 59.0 Ma (Fig. 1). This may be the best Paleogene nannofossil marker known in terms of reliability and worldwide applicability. (3) *D. multiradiatus* appears to reduce its ray number through time. This was first noted by MOSHKOVITZ (1967) when he first described Paleocene nannofossil assemblages from Israel. ROMEIN (1979) observed a similar phenomenon in a sedimentary section in Spain and another section in Israel. The major objectives of the present study are to determine whether the decrease in ray number of *D. multiradiatus* through time is consistent worldwide by examining material from different oceans and latitudes, and to calibrate the ray number change with magnetostratigraphy to explore the possible biochronological utility of this relationship.

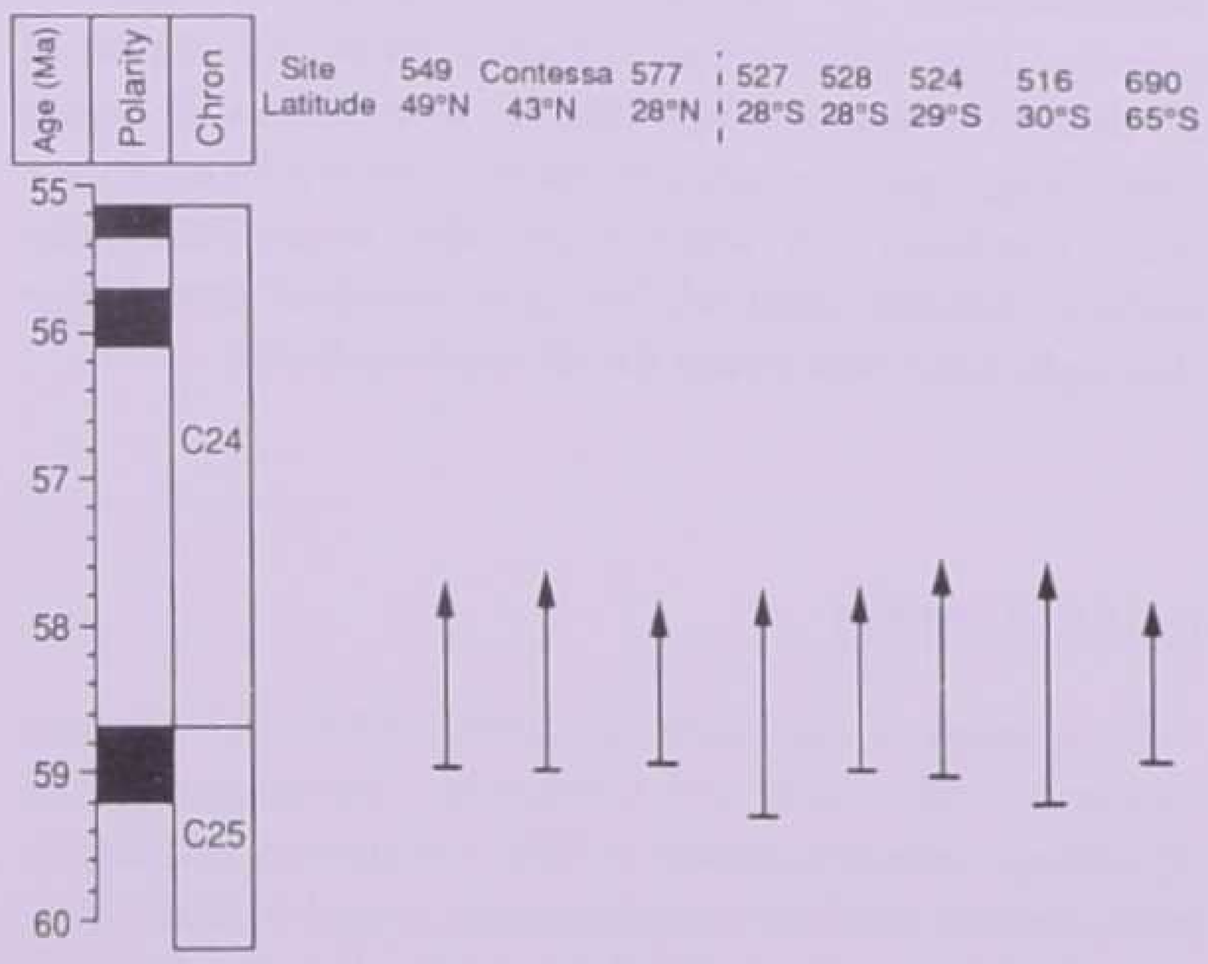

FIG. 1 - Correlation of the first occurrence of *Discoaster multiradiatus* with magnetostratigraphy (updated from WEI and WISE, 1989). Data sources: TOWNSEND (1985) and MÜLLER (1985) for DSDP Site 549; MONECHI and THIERSTEIN (1985) for Contessa; MONECHI *et al.* (1985) for DSDP Site 577; SHACKLETON *et al.* (1984) for DSDP Sites 527 and 528; POORE *et al.* (1984) for DSDP Site 524; WEI and WISE (1989) for DSDP Site 516; POSPICHAL and WISE (1990) for ODP Site 690.

MATERIAL AND METHODS

Samples from Deep Sea Drilling Project (DSDP) Sites 245 (Indian Ocean), 361,524,528 (South Atlantic), 577 (North Pacific), and 605 (North Atlantic) (Fig. 2) were analyzed in this study. Table 1 lists the locations of these sites and the DSDP *Initial Reports* where detailed sedimentological and paleontological information can be found. Biostratigraphic information for the

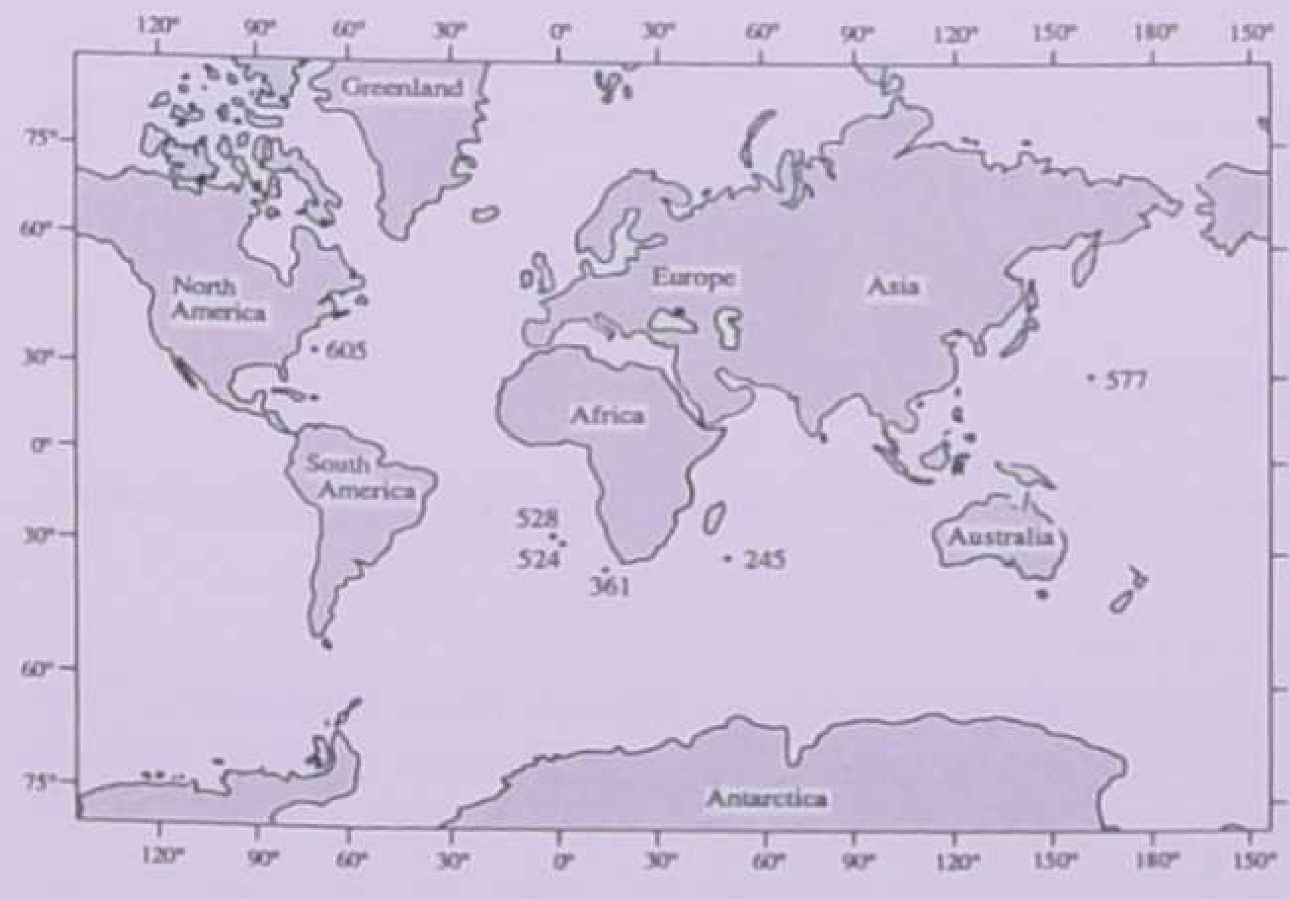

FIG. 2 - Location map of DSDP sites analyzed in this study.

TABLE 1 - Locations of DSDP sites used in this study and the references for these sites

Site	Latitude	Longitude	Reference for the site
245	31°32.02'S	52°18.11'E	SIMPSON, SCHLICH *et al.*, 1974
361	35°03.97'S	15°26.91'E	BOLLI, RYAN *et al.*, 1978
524	29°29.055'S	3°30.74'E	HSÜ, LA BRECQUE *et al.*, 1984
528	28°31.49'S	2°19.44'E	MOORE, RABINOWITZ *et al.*, 1984
577	32°26.51'N	157°43.40'E	HEATH, BURCKLE *et al.*, 1985
605	38°44.53'N	72°36.55'W	VAN HINTE, WISE *et al.*, 1987

samples were mostly taken from these DSDP *Initial Reports*. However, the placement of the nannofossil datums were rechecked during this study, and some revisions were made (see discussion below). The age model shown in Figure 3

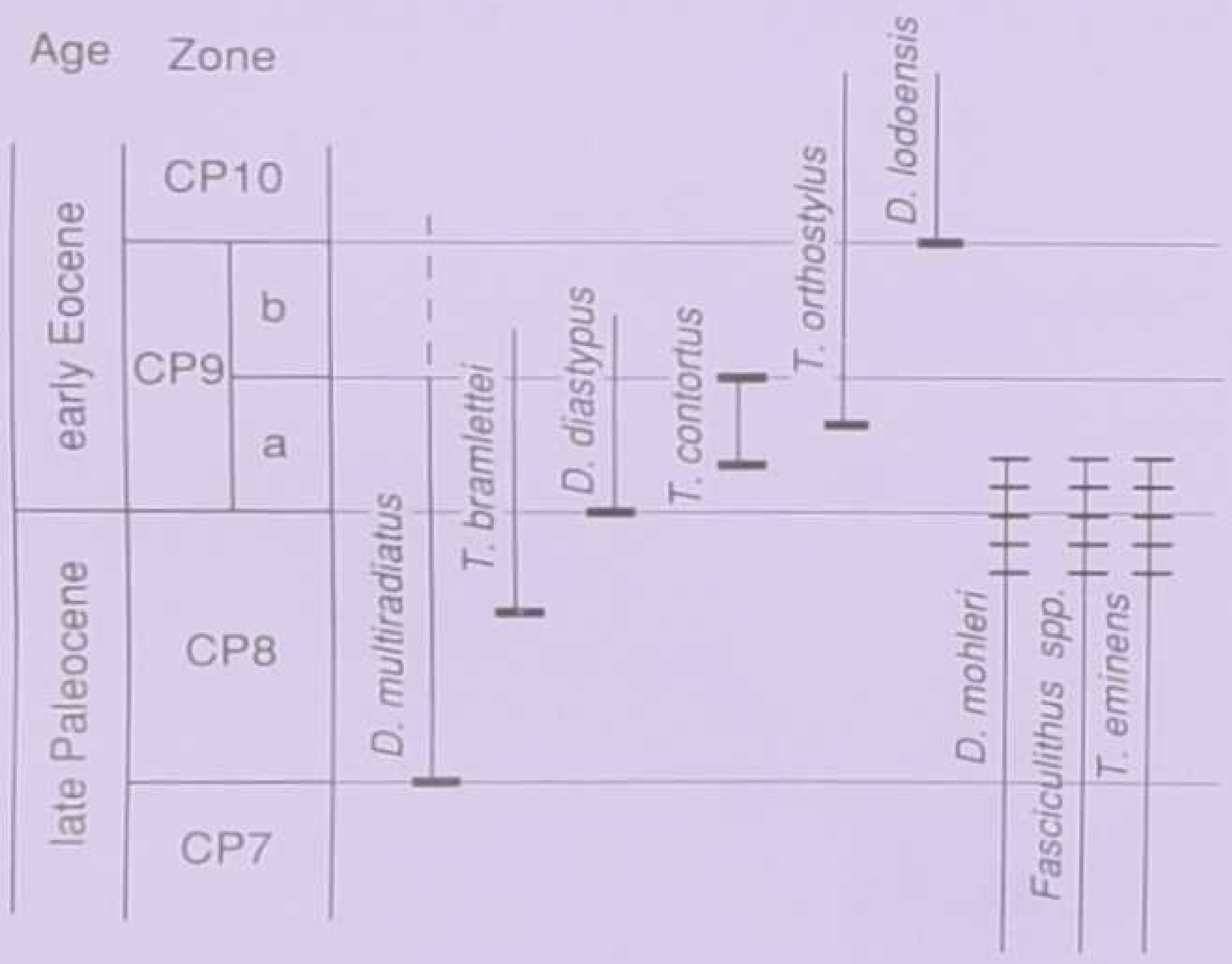

FIG. 3 - The age model used in this study to evaluate the nannofossil biostratigraphic information taken from the DSDP *Initial Reports*. The last occurrences of *Discoaster mohleri*, *Fasciculithus* spp., and *Toweius eminens* fluctuate around the CP8/CP9 boundary.

was used to evaluate the biostratigraphic information. Further discussion of the nannofossil datums for the upper Paleocene to lower Eocene are presented in the appendix of this paper. In addition to biostratigraphy, magnetostratigraphic information was available for Sites 524, 528, and 577. This makes the assignments of numerical ages for the samples from these three sites possible. For easy comparison of this study with most previous studies, the time scale of BERGGREN *et al.* (1985) is used in this paper.

In order to determine the mean ray number of *Discoaster multiradiatus* in each sample, the numbers of rays were counted for 30 or more specimens encountered during random traverses of a slide in a light microscope. Diameters of *D. multiradiatus* were measured in the light microscope for samples from two sites (245 and 605). Analyzing 30 or more specimens allows an estimation of the population mean with a known confidence level:

$$X \pm Z\alpha_{/2}(S/\sqrt{n})$$

where X is the mean of the measurements, S is the standard deviation of the measurements, n is the numbers of measurements, and $Z\alpha_{/2}$ is equal to 1.96 for a 95% confidence interval (MCCLAVE and DIETRICH, 1982).

MEAN RAY NUMBER CHANGE THROUGH TIME

SITE 245 (Fig. 4)

The core recovery rate at Site 245 is low (<50%) for the upper Paleocene-lower Eocene interval. BUKRY (1974) and MÜLLER (1974) zoned the samples recovered at this site, but did not give nannofossil range charts. Subsequently, MACKENZIE and WISE (1983) constructed range charts. The latter authors reported few *Discoaster diastypus* in Sample 245-9-2, 27-28 cm. However, no *D. diastypus* was found in this sample during this study. Some specimens of *Discoaster multiradiatus* with a prominent central stem were observed, which might have been taken as *D. diastypus* by the previous authors. These *D. multiradiatus* specimens have more than 22 rays and no free arms, which distinguish them from *D. diastypus*. Reexamination of samples from this site placed the FO o *D. diastypus* between Samples 245-9-1, 90-91 cm and -8-2, 105-107 cm, coinci-

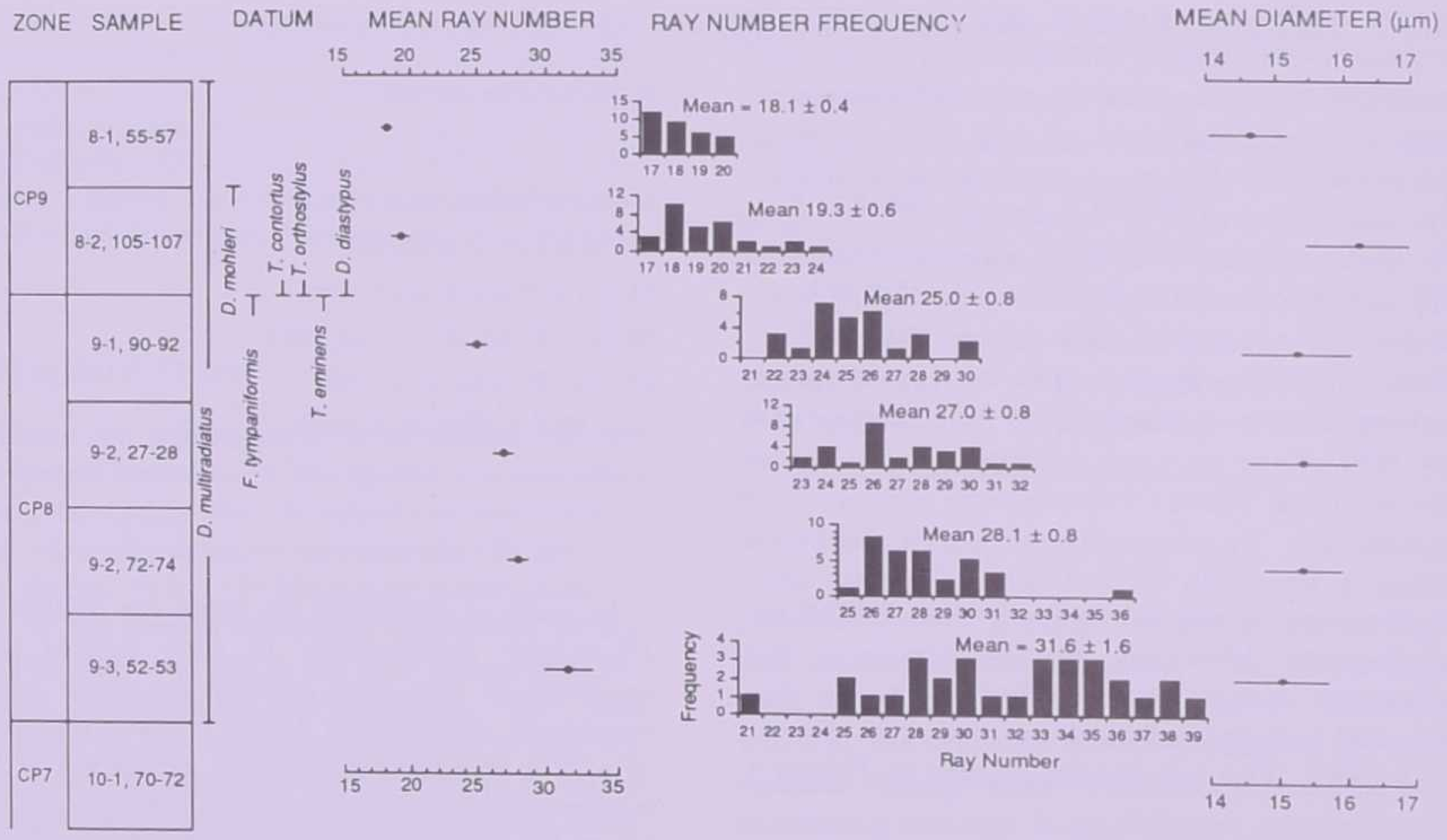

FIG. 4 - Biometric results of *Discoaster multiradiatus* at DSDP Site 245. Error bars denote 95% confidence intervals.

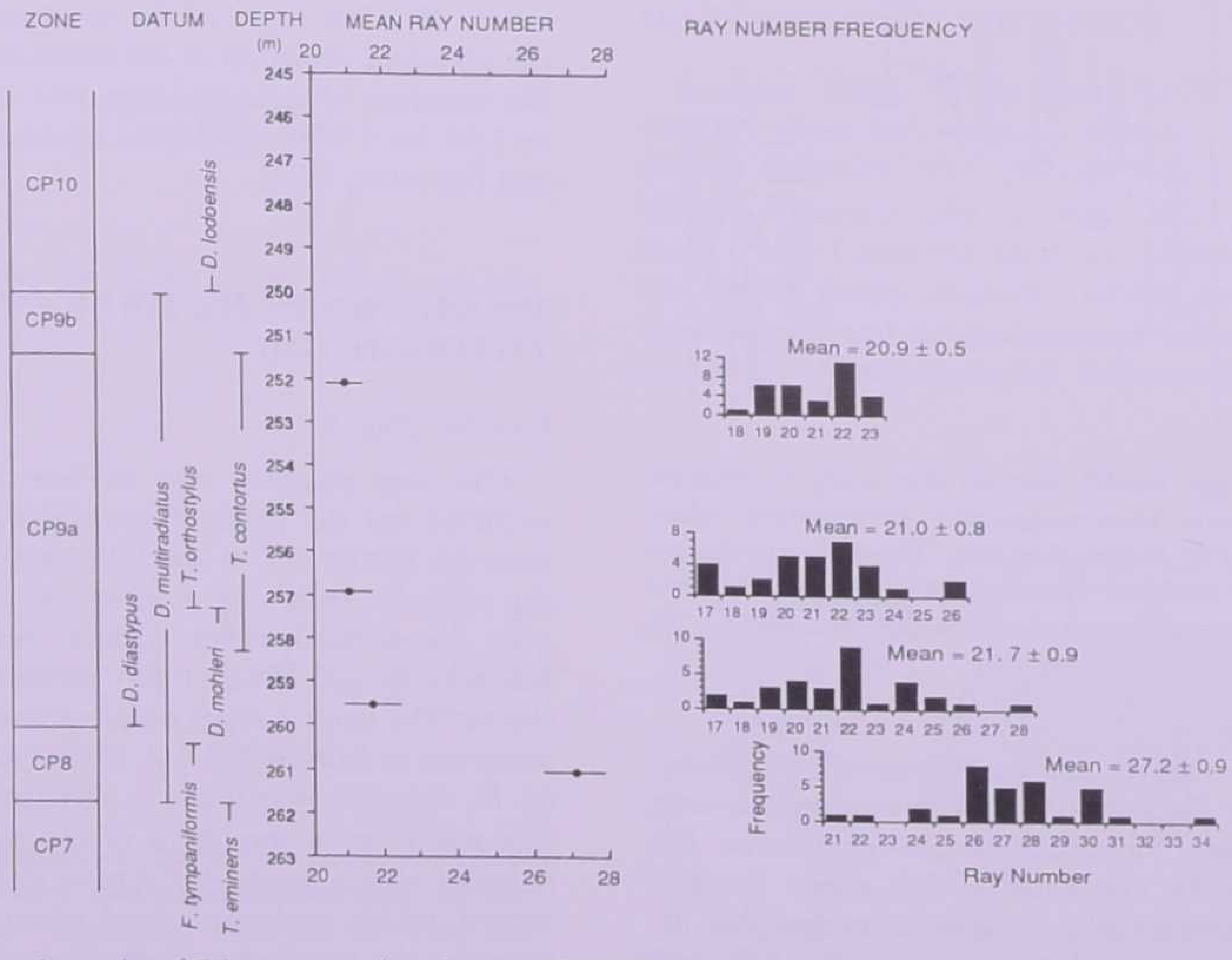

FIG. 5 - Biometric results of *Discoaster multiradiatus* at DSDP Site 361. Error bars denote 95% confidence intervals.

dent with the CP8/CP9 boundary recognized by BUKRY (1974) and the NP9/NP10 boundary drawn by MÜLLER (1974). The nannofossil datum levels given in Figure 4 represent the updated information, and the relative positions of the datums agree with the age model (Fig. 3).

Figure 4 reveals that the mean ray number of *Discoaster multiradiatus* at Site 245 decreases progressively from 31.6 near the bottom of Zone CP8 to 18.1 in Zone CP9. The histograms of ray number frequency show that the highest ray number and lowest ray number decrease through time, indicating a progressively shift in the whole population of *D. multiradiatus* toward fewer rays. However, the mean diameter of *D. multiradiatus* at Site 245 varies very little around 15 μm, and does not show a clear trend of change through time (Fig. 4).

SITE 361 (Fig. 5)

Calcareous nannofossil datum levels given in Figure 5 were taken from PROTO DECIMA *et al.* (1978). No *Tribrachiatus bramlettei* was found at this site, whereas the FO's of *Tribrachiatus contortus* and *Tribrachiatus orthostylus* were found 1.5 and 3 m above that of *Discoaster diastypus* respectively. On the other hand, the LO of *Fasciculithus tympaniformis* was found virtually concident with the FO of *D. diastypus*. The CP8/CP9

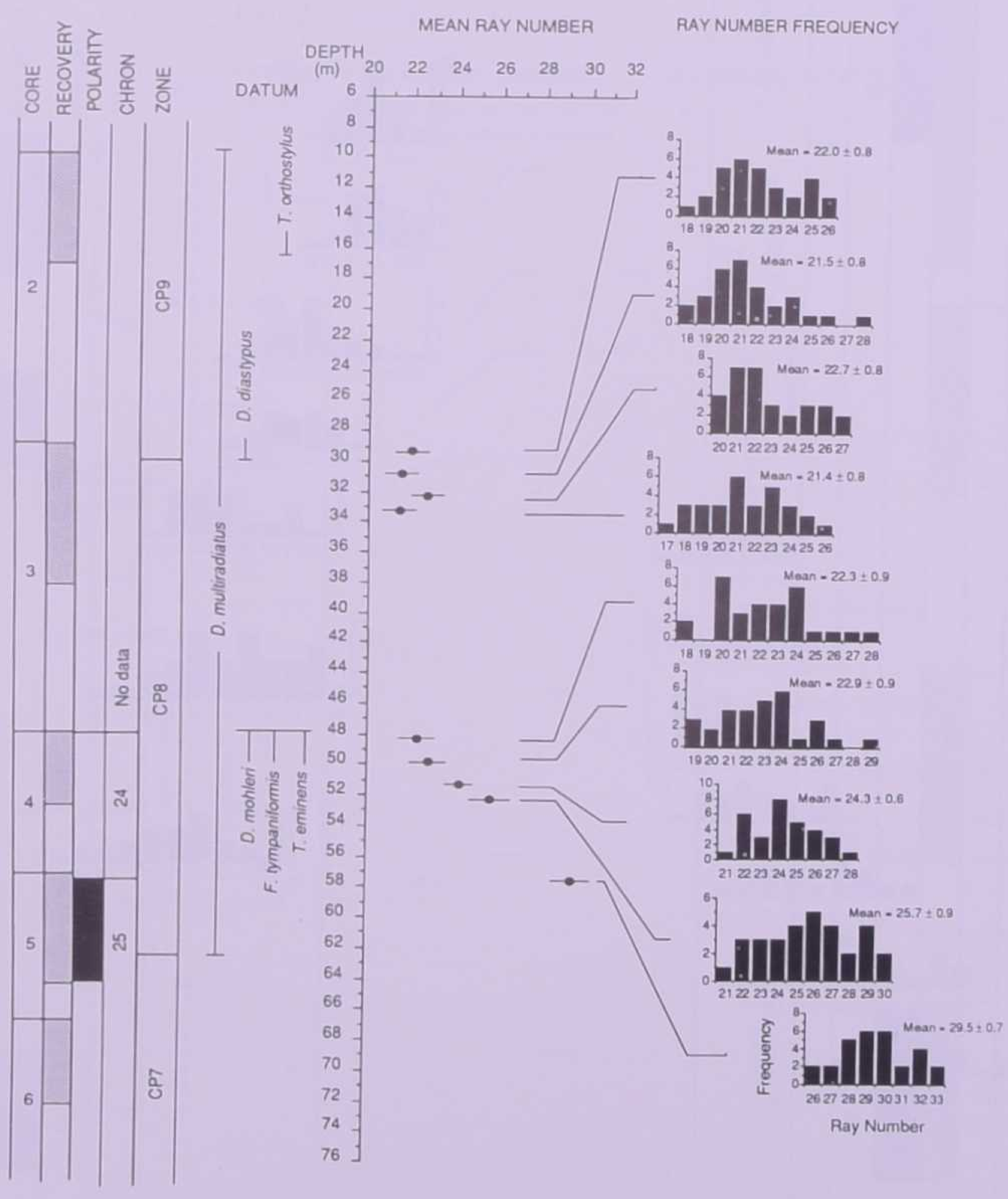

FIG. 6 - Biometric results of *Discoaster multiradiatus* at DSDP Site 524. Error bars denote 95% confidence intervals.

boundary drawn in Figure 5 is therefore believed to be fairly reliable. Only one sample from Zone CP8 was analyzed, which yielded a mean ray number of 27.2. Samples from Subzone CP9a yielded considerably lower mean ray numbers, from 21.7 to 20.9. It is notable, however, that the mean ray numbers of *D. multiradiatus* in Subzone CP9a at Site 361 appear to be slightly higher (1 to 2) than those of the same age at other sites.

SITE 524 (Fig. 6)

The calcareous nannofossil biostratigraphic information for Site 524 was taken primarily from PERCIVAL (1984), and the magnetostratigraphy of

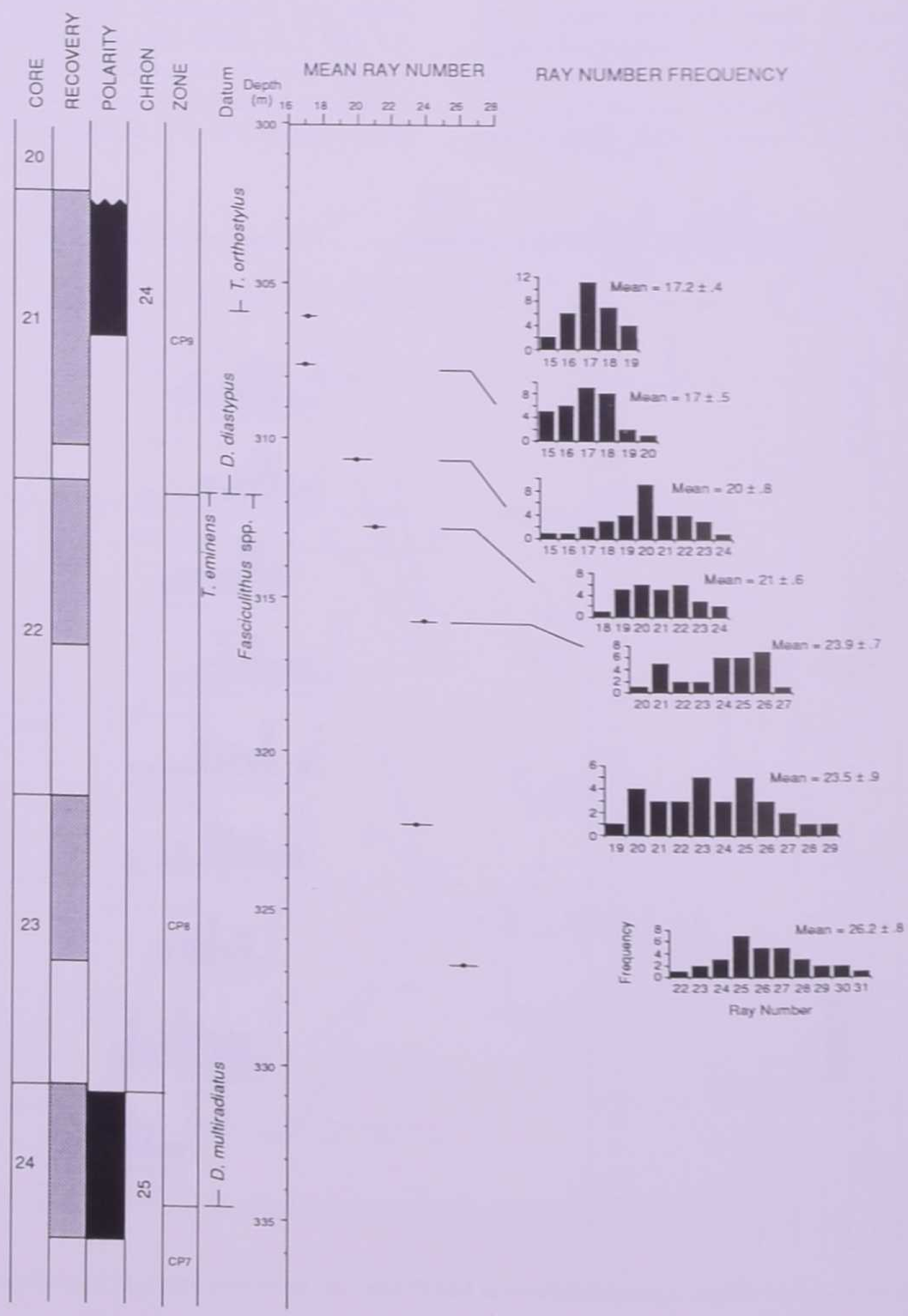

FIG. 7 - Biometric results of *Discoaster multiradiatus* at DSDP Site 528. Error bars denote 95% confidence intervals.

this site was based on POORE *et al.* (1984). No *Tribrachiatus bramlettei* or *Tribrachiatus contortus* was found at this site. Neither *Discoaster mohleri, Fasciculithus tympaniformis*, nor *Toweius eminens* was found to overlap in range with *Discoaster diastypus* as in many other areas. Figure 6 shows that the mean ray number of *Discoaster multiradiatus* decreases from 29.5 near the bottom of Zone CP8 to 21-22 near the top of Zone CP8. This trend of decreasing mean ray number through time is most apparent in the lower part of Zone CP8 and less apparent in the upper part of Zone CP8.

SITE 528 (Fig. 7)

The placements of nannofossil datums in Figure 7 for Site 528 were based on BACKMAN (1986), whereas the magnetostratigraphic information was taken from SHACKLETON *et al.* (1984). The LO of *Fasciculithus* spp. coincides with the FO of *Discoaster diastypus* at this site. As at Site 524, neither *Tribrachiatus bramlettei* nor *Tribrachiatus contortus* was found at Site 528. Mean ray number of *Discoaster multiradiatus* decreases progressively from 26.2 in the lower part of Zone CP8 to 17.2 in Zone CP9, and is in good agreement with results from other sites.

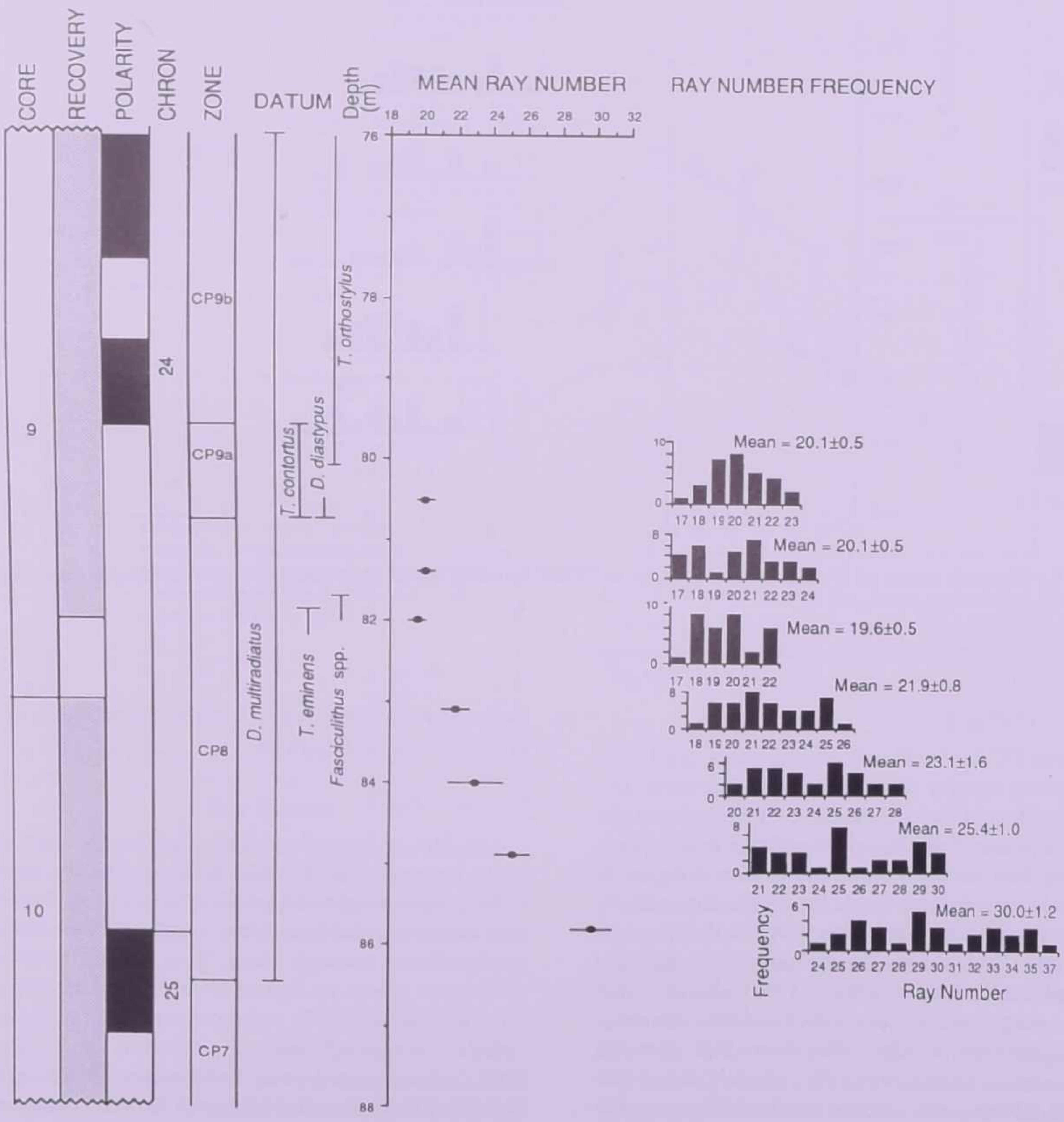

FIG. 8 - Biometric results of *Discoaster multiradiatus* at DSDP Site 577. Error bars denote 95% confidence intervals.

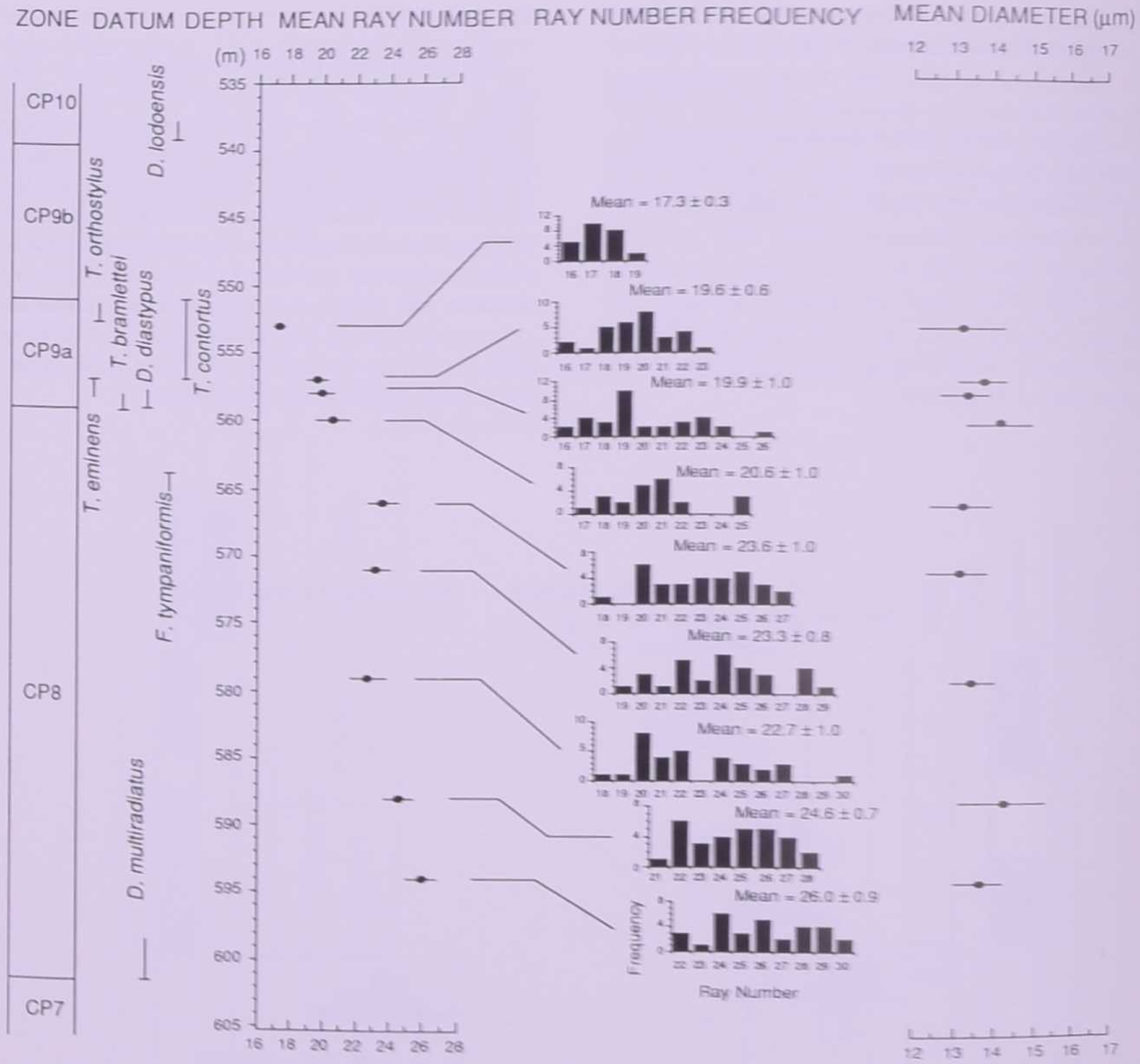

FIG. 9 - Biometric results of *Discoaster multiradiatus* at DSDP Site 605. Error bars denote 95% confidence intervals.

SITE 577 (Fig. 8)

Site 577 in the North Pacific has a good core recovery rate for the upper Paleocene-lower Eocene. Most of the commonly used nannofossil datums except *Tribrachiatus bramlettei* were reported by BACKMAN (1986) and are shown in Figure 8. In addition, data for the LO's of *Toweius eminens* and *Fasciculithus* spp. were taken from MONECHI (1985). Excellent magnetostratigraphic data are available at this Site (BLEIL, 1985). Again, mean ray number of *Discoaster multiradiatus* decreases progressively through time, from 30.0 near the bottom of Zone CP8 to 20.1 slightly above the CP8/CP9 boundary. As at other sites, a progressive shift in the whole population of *D. multiradiatus* toward fewer rays is clear from the histograms shown in Figure 8.

SITE 605 (Fig. 9)

Site 605 is located on the continental rise off New Jersey in the North Atlantic Ocean. Zone CP8 is quite expanded (<40 m), offering higher resolution for the biometric study of *Discoaster multiradiatus* through time. The nannofossil datum levels given in Figure 9 are those of APPLEGATE and WISE (1987) except for the LO of *Fasciculithus tympaniformis*. APPLEGATE and WISE (1987) reported common *F. tympaniformis* up to Sample 605-43,2, 110-112 cm (550.5 m). However, this species was found only up to Sample 605-

44-5, 56-58 cm (564.0 m) during this study. Broken and overgrown *Zygrhablithus bijugatus* which resemble *F. tympaniformis* are common further up the section, including sample 605-43-2, 110-112 cm, and might have been recorded as *F. tympaniformis* in the previous study. Figure 9 shows that the FO of *Tribrachiatus bramlettei* coincides with that of *Discoaster diastypus*, and this is slightly different from the age model (Fig. 3). A trend of decrease in mean ray number of *D. multiradiatus* through time is apparent in Figure 9. However, as at Site 245, no clear trend of mean diameter change through time can be seen at Site 605. It is interesting to note that the average mean diameter for *D. multiradiatus* at Site 605 is slightly below 14 μm, whereas that at Site 245 is about 15.3 μm. The reason for this discrepancy between the two sites is not clear at this moment.

RELATIONSHIP BETWEEN DIAMETER AND RAY NUMBER

The diameter versus the ray number of *Discoaster multiradiatus* at Sites 245 and 605 were plotted in Figure 10. Figure 10 shows that diameter varies independently with ray number. This conclusion is in agreement with data published previously (MOSHKOVITZ, 1967; ROMEIN, 1979).

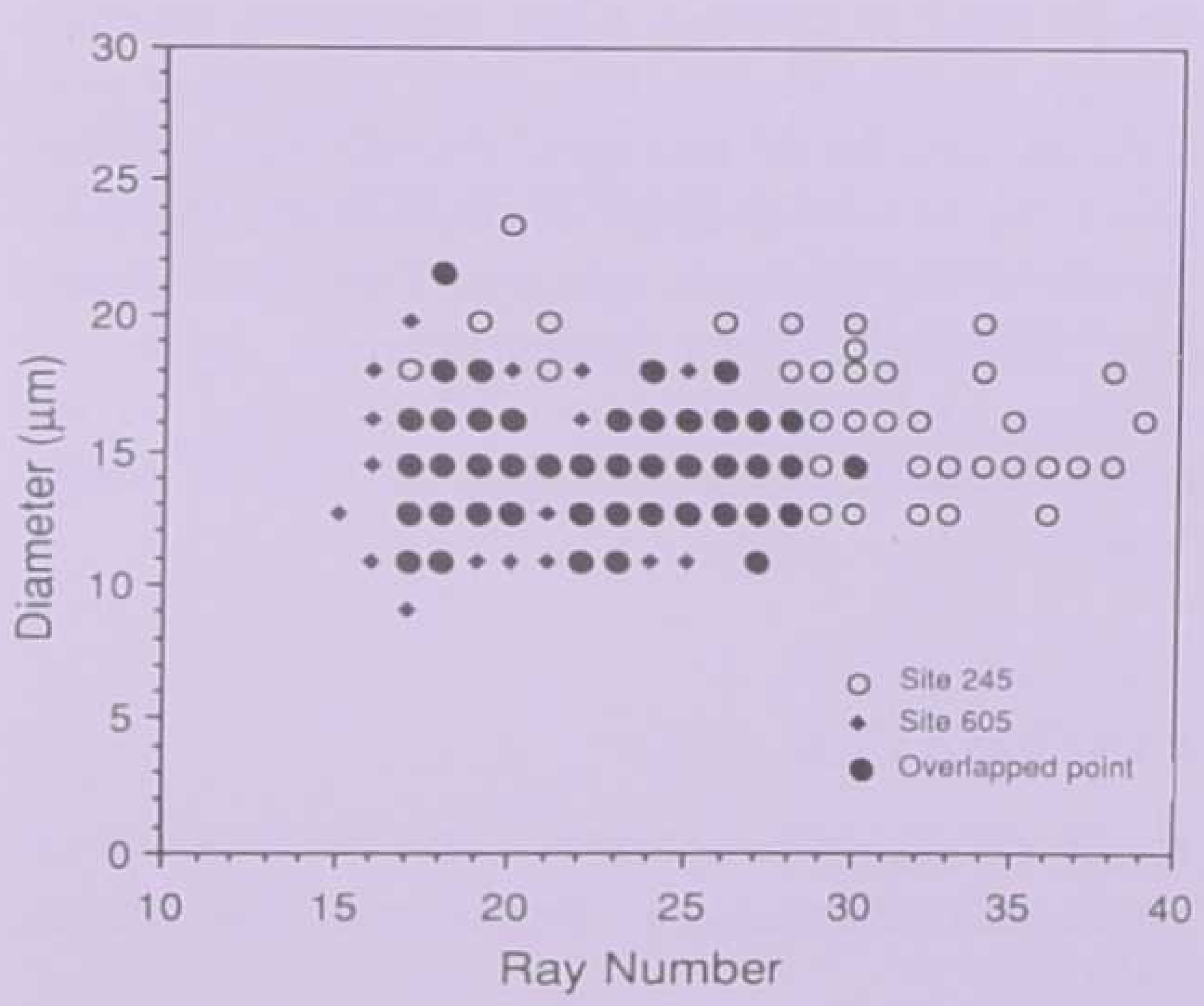

FIG. 10 - Diameter versus ray number for *Discoaster multiradiatus* at DSDP Sites 245 and 605. A total of 448 data points are plotted and each overlapped point shown in the figure may represent multiple data points.

CORRELATION OF MEAN RAY NUMBER CHANGE WITH MAGNETOSTRATIGRAPHY

For those three sites (524, 528, and 577) that have magnetostratigraphic data, it is useful to plot the mean ray number of *Discoaster multiradiatus* against the time scale of BERGGREN *et al.* (1985), assuming uniform sediment accumulation rates within each geomagnetic subchron recognized at the three sites. Figure 11 shows that the results of Site 524 in the South Atlantic agree quite well with those of Site 577 in the North Pacific, indicating that the reduction in the mean ray number of *D. multiradiatus* through time is virtually synchronous at the two sites. Results of Site 528 (the South Atlantic) agree fairly well with those of Sites 524 and 577 for the interval below 57.8 Ma. Above 57.8 Ma, results form Sites 528 and 577 appear to be less agreeable, although the general trend of reducing mean ray number through time is still true at both sites.

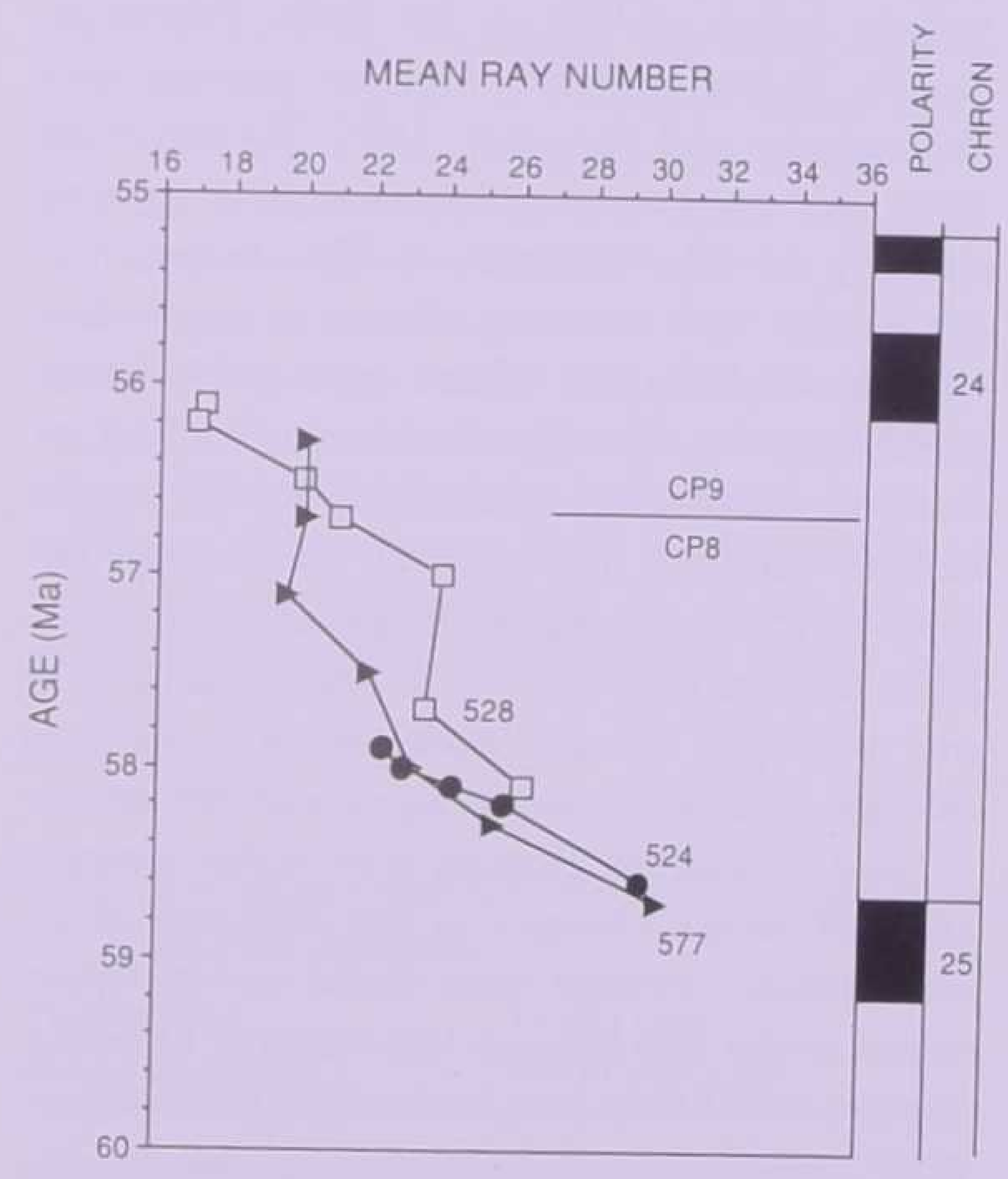

FIG. 11 - Correlation of the mean ray number change of *Discoaster multiradiatus* with the geomagnetic polarity time scale of BERGGREN *et al*, (1985), DSDP Sites 524, 528, and 577.

MORPHOMETRIC DEVELOPMENT VERSUS PALEOCLIMATIC CHANGE

Bukry (1971) discussed the evolutionary trends of *Discoaster*. He noted a general trend of progressively decreasing ray number in discoasters through the Tertiary, with 20 or 30 rays (*D. multiradiatus*) in the late Paleocene to 3 (*Discoaster triradiatus*) in the latest Pliocene. This coincided with a general cooling trend through the Tertiary. Bukry (1971) believed that *Discoaster* reduced its ray number and size to conserve more calcite in responding to a cooler climate.

Does the reduction of ray numbers in *D. multiradiatus* reflect cooling in the latest Paleocene-earliest Eocene interval? Oxygen isotopic data (Shackleton and Kennett, 1975; Miller *et al.*, 1987; and others) suggest instead a general warming for this time interval. This reduction of ray number with warming climate is opposite to what we might expect. There appear to be three possibilities for this: (1) climate was cooling instead of warming up as inferred by the oxygen isotopic data; (2) the general relationship between ray number and paleotemperature for *Discoaster* does not hold true for *D. multiradiatus*; (3) the thickness of *D. multiradiatus* increases through time, which would agree with the general trend of more calcification with higher temperature. However, changes in the thickness of *D. multiradiatus* through time could not be determined in this tudy because side views of *D. multiradiatus* were rarely seen in the light microscope.

0800 Some specimens of *Discoaster multiradiatus* have a prominent central stem (*i.e.*, Pl. I, Figs. 7, 8, 11), whereas some do not show any central stem at all (*i.e.*, Pl. I, Fig. 9). Romein (1979) believed that the central stem represent the remnant of a cycle in *Heliolithus*. Perch-Nielsen (1985, p 469) stated that a central stem developed as *D. multiradiatus* evolved. Data from this study, however, appear to suggest otherwise, that is, more specimens of *D. multiradiatus* with a central stem were found lower in the sections. It was also noted during this study that more specimens of *D. multiradiatus* posses a central stem in the higher latitude sites, whereas very few specimens of *D. multiradiatus* show a central stem at Site 577 (an equatorial site in the Paleogene). This seems to suggest that individuals of *D. multiradiatus* with a central stem preferred cooler waters, and this general trend appears to be true through both time and space for the material of this study.

SUMMARY

Analyses of material from six DSDP sites in the northern Indian Ocean, the South Atlantic, the North Atlantic, and the North Pacific demonstrated that the general trend of decreasing in mean ray number of *Discoaster multiradiatus* through time is consistent worldwide. Mean ray number changes through time were calibrated with magnetostratigraphy at Sites 524, 528 (South Atlantic), and 577 (North Pacific). Results are relatively consistent among the three sites, particularly for the interval of 57.7-58.7 Ma. Results from the six sites show that *D. multiradiatus* with mean ray number less than 19 belong to Zone CP9, those with mean ray numbers between 19 and 22 are within the vicinity of CP8/CP9 boundary, those with mean ray number greater than 22 fall into Zone CP8, and those with mean ray numbers of around 30 are from the bottom part of Zone CP8. This relationship between mean ray number of *D. multiradiatus* and age enables a considerably higher biostratigraphic resolution than ordinary biostratigraphic methods can achieve for the latest Paleocene-earliest Eocene interval, and this is possible even when other marker species are not found. This study has shown a good example of how biometric studies can be used to achieve high resolution biochronology. Similar studies for other calcareous nannofossil species or lineages should help to improve the biostratigraphic resolution for many intervals in the geologic column. This study found that diameter varies independently with ray number, and there is not a clear trend in the mean diameter change through time for *D. multiradiatus*.

SYSTEMATICS

Genus *Discoaster* Tan, 1927

Discoaster multiradiatus Bramlette and Riedel, 1954

(Pl. I, Figs. 1-12)

Discoaster multiradiatus Bramlette and Riedel, 1954, p. 396, pl. 38, fig. 10; Bramlette and Sullivan, 1961, p. 161, pl. 12, fig. 10; Haq and Lohmann, 1976, p. 142, pl. 2, figs. 3-6; Wise and Wind, 1977, p. 347, pl. 17, fig. 2; Romein, 1979, p. 221, pl. 6, figs. 1-3; Steinmetz and Stradner, 1984, p. 733, pl. 34, fig. 9.

Discoaster aff. *D. multiradiatus* Bramlette and Riedel, Perch-Nielsen, 1972, p. 1053, pl. 14, fig. 5.

Discoaster sp. 3 PERCH-NIELSEN, 1972, p. 1053, pl. 14, fig. 2.
Discoaster barbadiensis TAN, MACKENZIE and WISE, 1983, pl. 10., fig. 3.
Discoaster elegans BRAMLETTE and SULLIVAN, PERCH-NIELSEN, 1972, p. 1053, pl. 14, fig. 6.
Discoaster perpolithus MARTINI, 1961, p. 9, pl. 2, fig. 20; pl. 5, fig. 50; SULLIVAN, 1964, p. 43, pl. 10, fig. 12; ROMEIN, 1979, p. 167, pl. 6, fig. 4.

Remark: *Discoaster multiradiatus* was described from Velasco Shale of Mexico, which was believed then to be Paleocene or Cretaceous (BRAMLETTE and RIEDEL, 1954, p. 396). BRAMLETTE and RIEDEL (1954) described the species as "consisting of usually (16-24 rays" and with "diameter usually 9-15 microns". As discussed above, *D. multiradiatus* occurs only in upper Paleocene to lower Eocene sediments and the FO of this species has a very consistent age of above 59.0 Ma worldwide. During this study, ray number as high as 39 and diameter up to 24 μm were recorded (Fig. 10). The lower end ray number for *D. multiradiatus* was taken as 15 in this study, and this minimum number probably represents an artificial cutoff from *Discoaster barbadiensis*. As *D. multiradiatus* appears to overlap in range with *D. barbadiensis* and the former species appear to grade into the latter, the last occurrence of *D. multiradiatus* is therefore difficult to locate and is considered unreliable, as can be seen in Figs. 4-9 and Figure 12 (A-F) in the appendix.

APPENDIX

This appendix discusses the major calcareous nannofossil datums within and slightly above the biostratigraphic range of *Discoaster multiradiatus*. In addition to Figures 4-9, Figure 12 (A-F) shows graphically the relative positions of the nannofossil datums in a number of fairly complete upper Paleocene-lower Eocene sequences from different regions. Figures 4-9 and 12 show that *Tribrachiatus bramlettei* was found at DSDP Site 605 (Fig. 9), in the Possagno section (Italy, Fig. 12A), the Caravaca section (Spain, Fig. 12C), and the Nahal Avdat section (Israel, Fig. 12D), but was not found at DSDP Sites 245 (Fig. 4), 361 (Fig. 5), 524 (Fig. 6), 528 (Fig. 7), 577 (Fig. 8), 277 (Fig. 12B), or 386 (Fig. 12E). On the other hand, *Discoaster diastypus* is present at all of these sites and in all of the land sections mentioned above. Furthermore, there is often confusion with the identification of *T. bramlettei* vs. *Rhombaster*, and JIANG and WISE (1987) have

TABLE 2 - Relative positions of the last occurrences (LO) of *Discoaster mohleri, Fasciculithus* spp., and *Toweius eminens* in relation to the first occurrence (FO) of *Discoaster diastypus*.

Datum	Coincident with FO *D. diastypus*	Higher than FO *D. diastypus*	Lower than FO *D. diastypus*
LO *D. mohleri*		Site 245 (Fig. 4)	Site 524 (Fig. 6)
		Site 361 (Fig. 5)	Spain (Fig. 12C)
			Israel (Fig. 12D)
	Site 386 (Fig. 12E)		
			Site 549 (Fig. 12F)
LO *Fasciculithus* spp.	Site 245 (Fig. 4)	Italy (Fig. 12A)	Site 361 (Fig. 5)
	Site 528 (Fig. 7)	Israel (Fig. 12D)	Site 524 (Fig. 6)
		Site 368 (FIg. 12E)	Site 577 (Fig. 8)
		Site 549 (Fig. 12F)	Site 605 (fig. 9)
		Site 277 (Fig. 12B)	
		Spain (Fig. 12C)	
LO *T. eminens*	Site 245 (Fig. 4)	Site 605 (Fig. 9)	Site 361 (Fig. 5)
		Italy (Fig. 12A)	Site 524 (Fig. 6)
		Spain (Fig. 12C)	Site 577 (Fig. 8)
		Israel (Fig. 12D	
		Site 549 (Fig. 12F)	

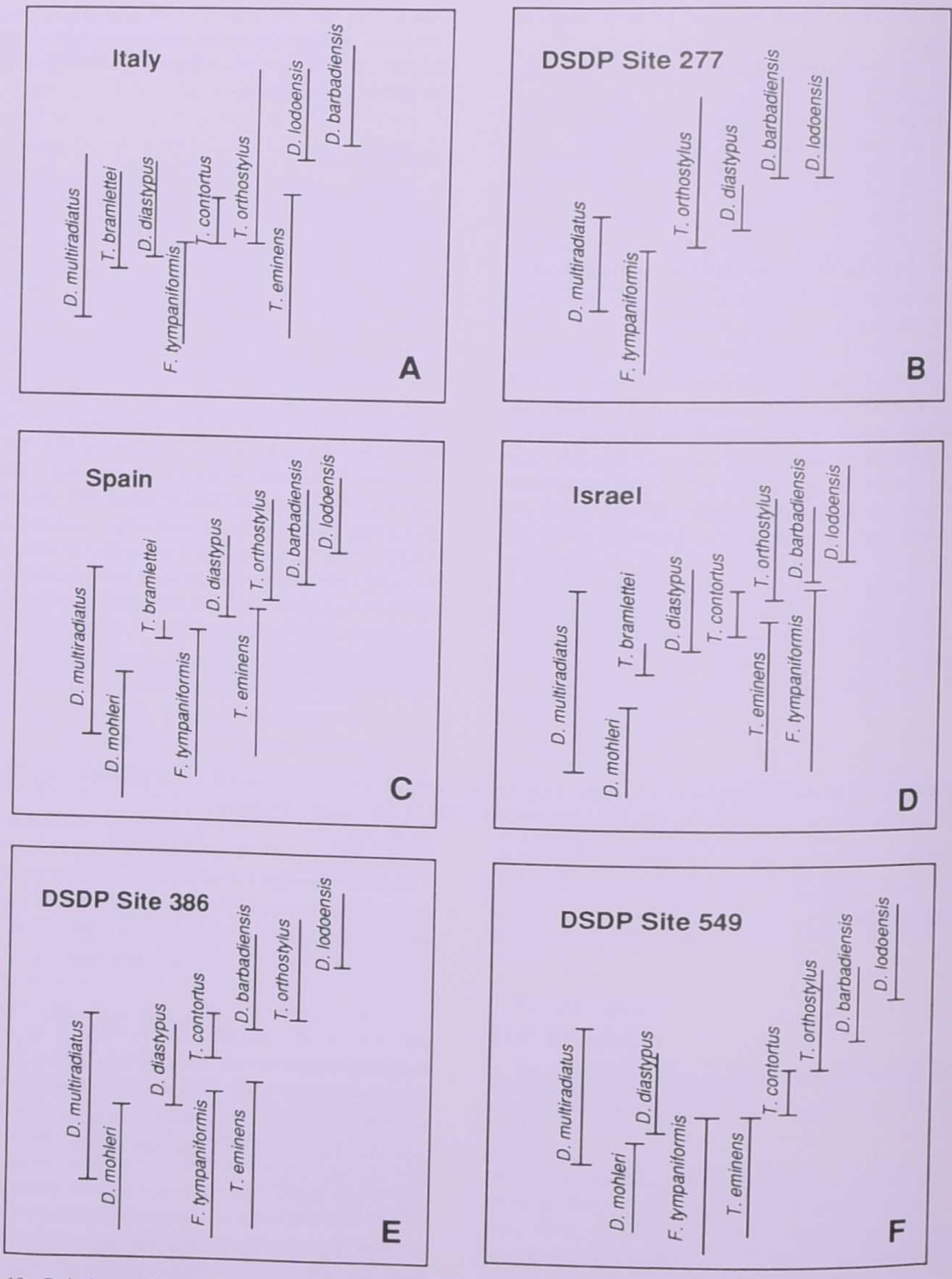

FIG. 12 - Relative positions of calcareous nannofossil datums at various sites. (A), Possagno section (Italy); data are taken from PROTO DECIMA *et al.* (1975). (B), DSDP Site 277; data are taken from EDWARDS and PERCH-NIELSEN (1975), (C), the Caravaca section (Spain); data are taken from ROMEIN (1979). (D), the Nahal Avdat section (Spain); data are taken from ROMEIN (1979). (E), DSDP Site 386; data are taken from OKADA and THIERSTEIN (1979). (F), DSDP Site 549; data are taken from MÜLLER (1985).

showed that overgrowth can strongly change the appearance of *T. bramlettei* in offshore vs near-shore localities. Thus, the FO of *D. diastypus* is believed to be a more reliable datum than the FO of *T. bramlettei*. The above figures also show that the FO of *D. diastypus* is stratigraphically higher than that of *T. bramlettei*. That means the CP8/CP9 zonal boundary is stratigraphically higher than the NP9/NP10 boundary. Correlations of the FO of *D. diastypus* with magnetostratigraphies at DSDP Sites 528 and 577 indicate a relatively consistent age of about 56.7 Ma. The LO's of *Discoaster mohleri*, *Fasciculithus* spp., and *Toweius eminens* fluctuate around the FO of *D. diastypus* from site to site, which is summarized in Table 2. *Discoaster multiradiatus* was reported to overlap in range with *Discoaster barbadiensis* in the Caravaca section (Spain, Fig. 12C), at DSDP Site 386 (Fig. 12E) and Site 549 (Fig. 12F), but no overlap was reported in the Possagno section (Italy, Fig. 12A), the Nahal Avdat section (Israel, Fig. 12D) and at DSDP Site 277 (Fig. 12B). This discrepancy reflects the difficulty of picking the LO of *D. multiradiatus* and the FO of *D. barbadiensis*, and is due to the fact that these two forms appear to be gradational.

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EXPLANATION OF PLATE I

FIGS. 1-12 - *Discoaster multiradiatus* BRAMLETTE and RIEDEL, 1954. Note the variations in the number of rays and a prominent central stem in some specimens.

FIG. 1 - 5,000 X, Sample 245-91, 90-92 cm.

FIG. 2 - 3,500X, Sample 245-91, 90-92 cm.

FIG. 3 - 5,500X, Sample 516F-83-6, 51-52 cm.

FIG. 4 - 3,00X, Sample 245-91, 90-92 cm.

FIG. 5 - 3,500X, Sampler 245-91, 90-92 cm.

FIG. 6 - 3,000X, Sample 245-91, 90-92 cm.

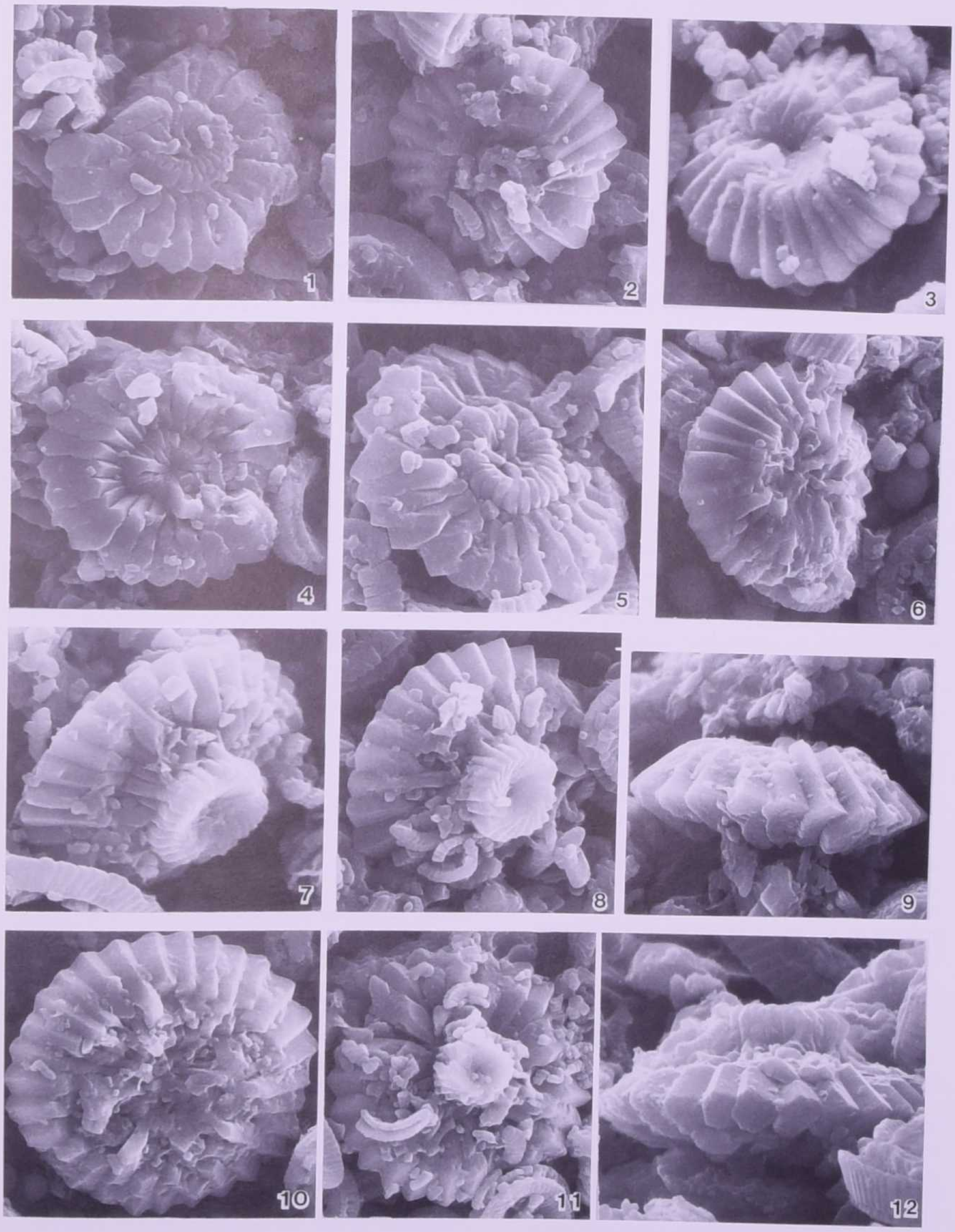
FIG. 7 - 4,500X, Sample 524-4-4- 29-30 cm.

FIG. 8 - 5,000X, Sample 524-4-4, 29-30 cm.

FIG. 9 - 3,000X, Sample 524-4-4, 29-30 cm.

FIGS. 10-11 - 3,500X, Sample 524-4-4, 29-30 cm.

FIG. 12 - 6,000X, Sample 524-4-4, 29-30 cm.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