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OLIGOCENE/MIOCENE MORPHOMETRIC VARIABILITY OF THE *CYCLICARGOLITHUS* GROUP FROM THE EQUATORIAL ATLANTIC AND INDIAN OCEANS

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Key words: Oligocene, Miocene, Cyclicargolithus, morphometry, equatorial Atlantic Ocean, equatorial Indian Ocean.

ABSTRACT

Measurements of late Oligocene and early to middle Miocene members of the genus *Cyclicargolithus* from Ocean Drilling Program (ODP) Hole 667A in the equatorial Atlantic Ocean and Hole 709C in the equatorial Indian Ocean show that the diameter of the specimens varies from less than 4 to over 14 µm. The mean diameter ranges from 5.9 to 8.9 µm. Variations in the mean diameter of the *Cyclicargolithus* group are similar in both basins during late Oligocene and early Miocene times.

Based on plots of the size distribution within *Cyclicargolithus* assemblages from different stratigraphical levels, it is possible to divide the *Cyclicargolithus* group into two size groups. One of the size groups (group A) has specimen diameters less than 11 µm and constitutes the main body of the *Cyclicargolithus* assemblage. The other group (group B) has specimen diameters greater than 11 µm and has a limited stratigraphic range in Zone CP19 in equatorial regions.

RIASSUNTO

Le misure effettuate su membri del genere *Cyclicargolithus* dell'Oligocene superiore e del Miocene inferiore e medio, provenienti dal pozzo 667A dell'Ocean Drilling Program nell'Atlantico equatoriale e dal pozzo 709C dell'Oceano Indiano equatoriale, mostrano che il diametro degli esemplari varia da meno di 4 µm a più di 14 µm. Il diametro medio è compreso fra 5.9 e 8.0 µm. Le variazioni nel diametro medio di *Cyclicargolithus* sono simili in entrambi i bacini durante l'Oligocene superiore e il Miocene inferiore.

Basandosi sui diagrammi della distribuzione dimensionale entro associazioni a *Cyclicargolithus* di livelli stratigrafici differenti è possibile dividere i *Cyclicargolithus* in due gruppi dimensionali. Uno di questi (gruppo A) ha il diametro degli esemplari inferiore a 11 µm e costituisce la massa principale delle associazioni a *Cyclicargolithus*. L'altro (gruppo B) ha il diametro degli esemplari maggiore di 11 µm ed una distribuzione stratigrafica limitata, nelle regioni equatoriali, alla Zona CP19.

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INTRODUCTION

The use of calcareous nannofossils for biostratigraphical purposes requires the adoption of consistent, preferably quantitative, definitions of the events used (BACKMAN, 1986a, 1986b; BACKMAN and SHACKLETON, 1983; FORNACIARI *et al.*, 1990; OLAFSSON, 1989, RIO *et al.*, 1990). In addition to this, strict taxonomic concepts must be used in order to increase the reliability of the marker events and maintain, or increase, the biostratigraphic consistency and resolution. Many nannofossil morphotypes show intermediate or transitional morphologies between forms that can be considered as end members of a lineage (BACKMAN and HERMELIN, 1986; MORAN and WATKINS, 1988). The end members are often easily identified, whereas problems arise when the intermediate morphologies are encountered. The use of different taxonomic concepts by different authors, a problem which becomes accentuated when considering intermediate morphologies, explains much of the difference in biostratigraphic ranges found in the literature.

One particular calcareous nannofossil event that has caused problems in biostratigraphy, is the "end of acme of *Cyclicargolithus abisectus*", which BUKRY (1973, 1975) used to define the top of the *Cyclicargolithus abisectus* Subzone, the CN1a/CN1b boundary of OKADA and BUKRY (1980). The problem of *C. abisectus* has two aspects:

First, BUKRY (1973, 1975) did not define the term "acme" quantitatively, thereby making it difficult for later investigators to use the event for biostratigraphical purposes. This is not a unique problem, since he used both "end of acme" and "beginning of acme" of different species to mark zonal boundaries without quantifying these quantitative concepts. Second, the taxonomy of the *Cyclicargolithus abisectus*/*Cyclicargolithus floridanus* group is problematic.

The original definition of *C. floridanus* describes an elliptic placolith that varies in size from 4.1 to 5 µm (ROTH and HAY in HAY *et al.*, 1967). BRAMLETTE and WILCOXON (1967) described *Cyclicargolithus neogammation* as a circular placolith with a diameter varying from 6 to 12 µm. Both these forms were described from upper Oligocene strata. MÜLLER (1970a) combined these two forms together with the Eocene form *Coccolithus marismontium* (BLACK, 1964) into *Cyclococcolithus floridanus* referring to a circular form 5-10 µm in diameter.

The original definition of *Coccolithus? abisectus* describes a circular to weakly elleptic placolith ranging in size from 8.5 to 11 µm (MÜLLER, 1970b). BUKRY and PERCIVAL (1971) placed this species in the genus *Dictyococcites* BLACK (1967), referring to a circular to subcircular placolith ranging in size from 12 to 16 µm and could be distinguished from *Cyclococcolithus neogammation* (BRAMLETTE and WILCOXON, 1967) by "its large size, thick collar cycle and discontinuous extinction lines" (BUKRY and PERCIVAL, 1971). BUKRY (1971) introduced the genus *Cyclicargolithus* as "circular to subcircular placoliths constructed of two shields connected by a central tube that may be closed or open" and assigned *Cyclococcolithus floridanus* to this genus. WISE (1973) recombined *Dictyococcites abisectus* to the genus *Cyclicargolithus* because in cross-polarized light it resembles *C. floridanus*.

It is virtually impossible to distinguish *C. floridanus* from *C. abisectus* using their original descriptions. The size ranges assigned to *C. abisectus* and *C. floridanus* overlap considerably, thus making it difficult to separate the two species by their described size ranges.

The appearance or optical behaviour of *C. abisectus* and *C. floridanus* is similar and a whole spectrum of intermediate morphologies is observed within the *Cyclicargolithus* group. The "collar cycle" and "discontinuous extinction lines" that BUKRY and PERCIVAL (1971) used to distinguish *D. abisectus* from *C. neogammation* are features that are highly dependent on the preservation state of the placoliths, and they become obscure in overgrown or dissolved specimens.

The purpose of this study is to use morphometric methods to investigate size distribution of the *Cyclicargolithus* group in the upper Oligocene and lower Miocene in tropical regions. Furthermore, an attempt is made to define the "end of acme of *C. abisectus*" that BUKRY (1973, 1975) used to mark the top of the *Cyclicargolithus abisectus* Subzone.

MATERIAL AND METHODS

Two equatorial sites have studied (Fig. 1). Hole 667A was drilled in the equatorial Atlantic Ocean (4°34.15'N, 21°54.68'W; water depth 3535 m, RUDDIMAN, SARNTHEIN, *et al.*, 1988) and Hole 709C was drilled in the equatorial Indian Ocean (3°54.9'S, 60°33.1'E; water depth 3038.2 m, BACKMAN, DUNCAN, *et al.*, 1988). The material spans the interval from Zone CP18 up through Subzone CN1c (OKADA and BUKRY, 1980). In Hole 667A, the interval was extended upwards to cover the last occurence of *C. floridanus* in Zone CN5 (OLAFSSON, 1989).

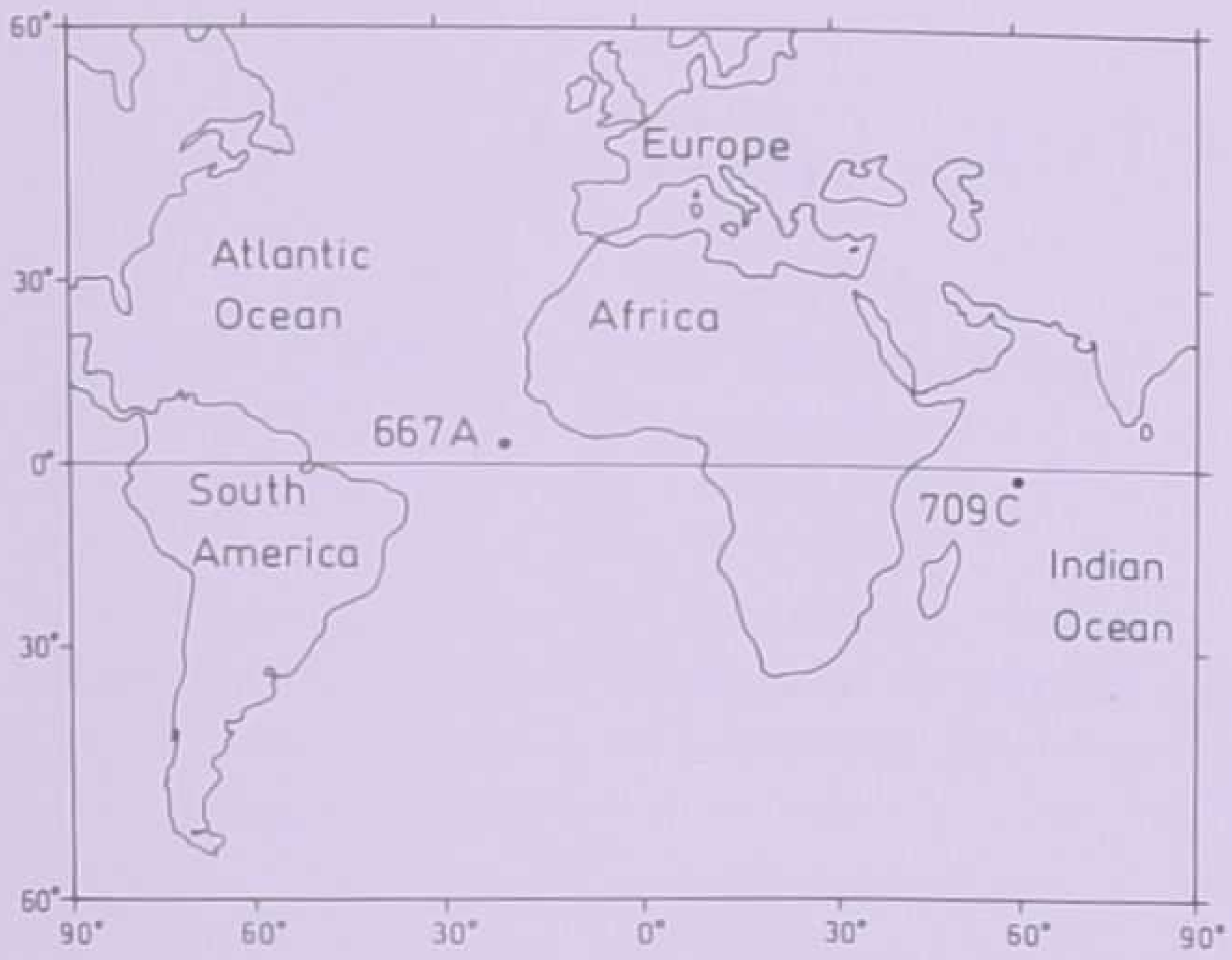

FIG. 1 - Location map showing the sites studied.

The distal shield diameter was measured in smear-slides, using an average sampling interval of 83 kyrs in Hole 667A and 150 kyrs in Hole 709C. No attempt was made to distinguish between *C. abisectus* and *C. floridanus*. The first 150 *Cyclicargolithus* placoliths that had a horizontal orientation in the smear-slide were measured, following a transect throughout the slide.

The measurements were made using a light-microscope connected to the image analyzing system described by GRANLUND and HERMELIN (1984). A total of 252 samples were studied this way, 200 from Hole 667A and 52 from Hole 709C. Measurements on a calibration micrometer with 10 μm between bars gave a mean value of 10.03 ± 0.30 μm (N = 50; 95% confidence interval). Increased numbers of measurements (up to 300 or 500) did not change these results, which indicates that a sample size of 150 specimens is sufficient to represent the whole size range of the *Cyclicargolithus* complex. Furthermore, the mean diameter becomes stable around 150 measurements (Tab. 1).

The nannofossil events used for the definitions of the zonal boundaries, together with their age estimates and depths in each site, are summarized in Table 2.

RESULTS FROM HOLE 667A

A scatter diagram where all measurements from Hole 667A are plotted against depth is shown in Figure 2. The diameter of *Cyclicargolithus* specimens ranges from 3.4 to 13.1 μm and the majority of the specimens has a diameter ranging between 4 and 8 μm. In the interval where morphotypes with a diameter >11 μm are continuously present (Zones CP19a and CP19b),

TABLE 1 - Change in the mean diameter (MD), size range, standard deviation (SD) and 95% confidence interval (95% CI) as a function of increased sample size. The sample shown is 115-709C-22-5/60 cm

N	MD	RANGE	SD	95% CI
25	7.70	4.72-12.23	1.75	0.69
50	7.21	4.72-12.23	1.48	0.41
75	7.26	4.72-12.23	1.46	0.33
100	7.42	4.72-12.23	1.44	0.28
125	7.44	4.72-12.23	1.45	0.26
150	7.43	4.72-12.23	1.44	0.23
175	7.38	4.66-12.45	1.50	0.22
200	7.36	4.66-12.45	1.48	0.21
225	7.35	4.63-12.45	1.49	0.19
250	7.35	4.63-12.45	1.49	0.19
275	7.31	4.63-12.45	1.46	0.17
300	7.32	4.63-12.45	1.48	0.17
325	7.33	4.63-12.45	1.48	0.16
350	7.39	4.63-14.55	1.55	0.16
375	7.38	4.63-14.55	1.55	0.16
400	7.37	4.63-14.55	1.54	0.15
425	7.35	4.63-14.55	1.52	0.15
450	7.37	4.63-14.55	1.52	0.14
475	7.39	4.63-14.55	1.56	0.14
500	7.39	4.63-14.55	1.55	0.15

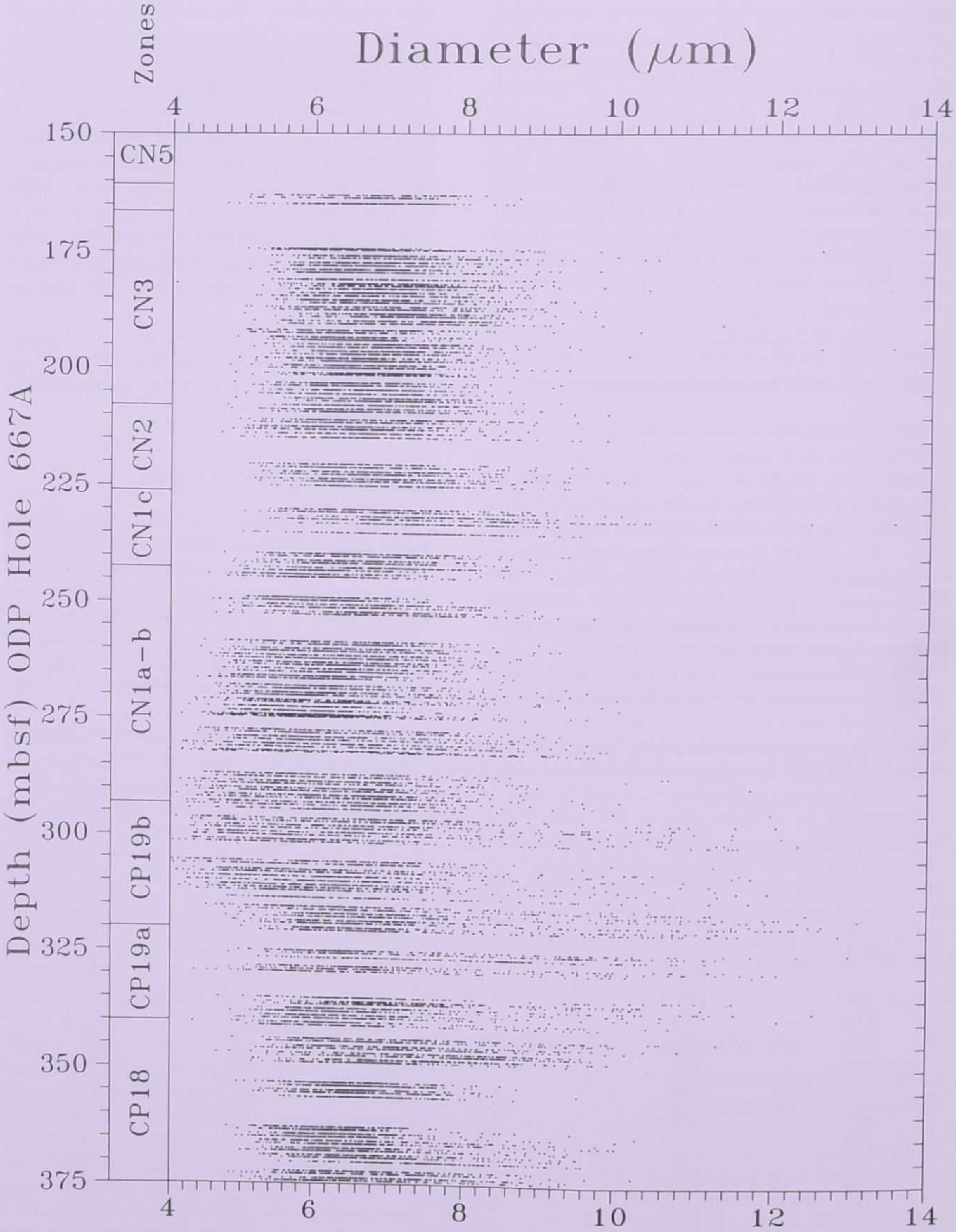

FIG. 2 - Scatter diagram where all the measured diameters are plotted against depth in Hole 667A. Gaps are caused by poor core recovery.

TABLE 2 - Nannofossil events used for the definitions of the zonal boundaries

Nannofossil event	Boundary	Age (Ma)	Depth (mbsf) 522[a]	667A[b]	709C[c]
S. heteromorphus[+]	CN4/CN5	13.60[d]	—	160.65	—
H. ampliaperta[+]	CN3/CN4	16.01[b]		166.40	—
*S. heteromorphus**	CN2/CN3	18.40[b]		207.85	—
*S. belemnos**	CN1c/CN2	20.00[d]	42.21[g]	227.25	170.35
D. druggii/T. serratus**	CN1b/CN1c	23.60[d]	51.45[g]	242.40	192.45
S. ciperoensis[+]	CP19a/CN1a	25.52[b]	64.05	293.20	200.05
*T. carinatus**		27.20[e]	—	313.10	210.50
S. distentus[+]	CP19a/CP19b	27.72[b]	76.00	319.89[h]	214.05
*S. ciperoensis**	CP18/CP19a	29.38[b]	84.80	340.03[h]	236.69
*S. distentus**	CP17/CP18	32.42[b]	104.00	376.90[h]	244.58

* First appearance; [+]Last occurrence; [a] OLAFSSON and VILLA, in press; [b] OLAFSSON, 1989; [c] FORNACIARI, *et al.*, 1990; [d] BACKMAN, *et al.*, 1990; [e] Based on the first appearance in ODP Hole 709C (FORNACIARI, *et al.*, (1990), using sphenolith ages obtained by OLAFSSON and VILLA (in press); [g] Extrapolated from *S. ciperoensis*[+]; [h] Extrapolated from *T. carinatus**.

morphotypes with diameter >9 µm are evenly scattered.

A plot of the mean diameter of *Cyclicargolithus* in Hole 667A is shown in Figure 3a, together with the distribution of specimens with diameters greater than (>) 9, 10 and 11 µm, respectively (Fig. 3b). This size group (>9 µm) is hereafter referred to as large morphotypes.

In Hole 667A the mean diameter of the *Cyclicargolithus* group ranges from 5.9 µm (Subzone CN1a-b, 272.25 mbsf) to 7.8 µm (Subzone CP19a, 326.25 mbsf). In Zone CP18 up to the lower part of Subzone CP19a the mean diameter is approximately 7 µm reaching a maximum value of 7.8 µm at 326.25 mbsf (Fig. 3a). Between 310 and 240 mbsf, an interval representing the upper part of Subzone CP19b and Subzone CN1a-b, the mean diameter is approximately 6.1 µm. In Subzone CN1c, the mean diameter increases again, and reaches a maximum just below the CN1c/CN2 boundary (Fig. 3a) before decreasing through Zone CN2 to approximately 6.4 µm at 212.25 mbsf. A maximum of 7.3 µm is again observed at 182.25 mbsf in the middle part of Zone CN3.

The lowermost occurrence of *Cyclicargolithus* specimens with a diameter ranging between 9 and 10 µm is at 375.55 mbsf (Fig. 3b). This size group is continuously present from the middle part of Zone CP18 and up to the lower part of Subzone CN1a-b but throughout the rest of the interval investigated it occurs sporadically and in low numbers (Fig. 3b).

The lowermost observation of *Cyclicargolithus* specimens with diameter between 10 and 11 µm was made at 374.8 mbsf in the upper part of Zone CP18 (Fig. 3b). Above 339 mbsf they are continuously present up to the CP19b/CN1 boundary at 293.20 mbsf. Throughout the remainder of the investigated interval, up to Zone CN3, where the last *Cyclicargolithus* specimen with diameter between 10 and 11 µm was observed (174.25 mbsf), they occur sporadically and in low abundances (Fig. 3b).

The lowermost occurrence (one specimen) of *Cyclicargolithus* specimens >11 µm is at 343.75 mbsf in the upper part of Zone CP18 (Fig. 3b). They are continuously present from the lowermost part of Subzone CP19a (338.7 mbsf) up to the CP19a/CN1 boundary at 293.20 mbsf. No specimen of *Cyclicargolithus* >11 µm was observed at higher levels.

The size distribution of *Cyclicargolithus* in selected samples from Hole 667A shows a more or less normal distribution where forms with a diameter >10 µm are absent (Fig. 4a and 4b). In the majority of the samples from Hole 667A, the greatest part of *Cyclicargolithus* specimens has a diameter ranging between 5 and 8 µm (represented by Sample A in Fig. 4a). In some samples the specimens are somewhat larger, and the majority of the specimens has a diameter ranging between 6 and 9 µm (represented by Sample B in Fig. 4b). This reflects a decrease of 15% in the mean diameter from Subzone CN1c (Fig. 4b) to Zone CN3 (Fig. 4a).

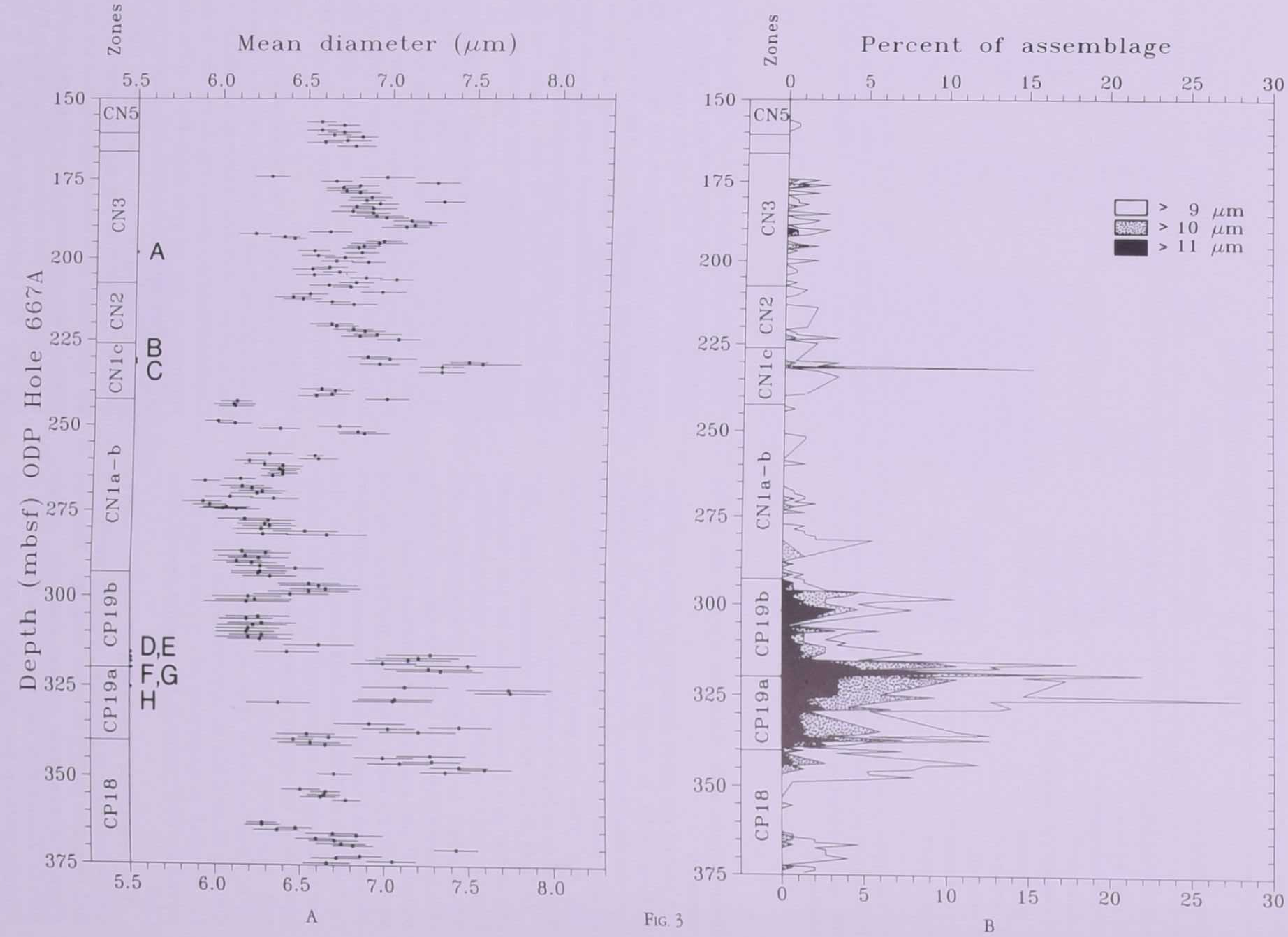
Depth (mbsf) ODP Hole 667A
Zones
Mean diameter (μm)
5.5
6.0
6.5
7.0
7.5
8.0
150
175
200
225
250
275
300
325
350
375
CN5
CN3
CN2
CN1c
CN1a–b
CP19b
CP19a
CP18
A
B
C
D,E
F,G
H
A
Percent of assemblage
0
5
10
15
20
25
30
> 9 μm
> 10 μm
> 11 μm
B

Fig. 3

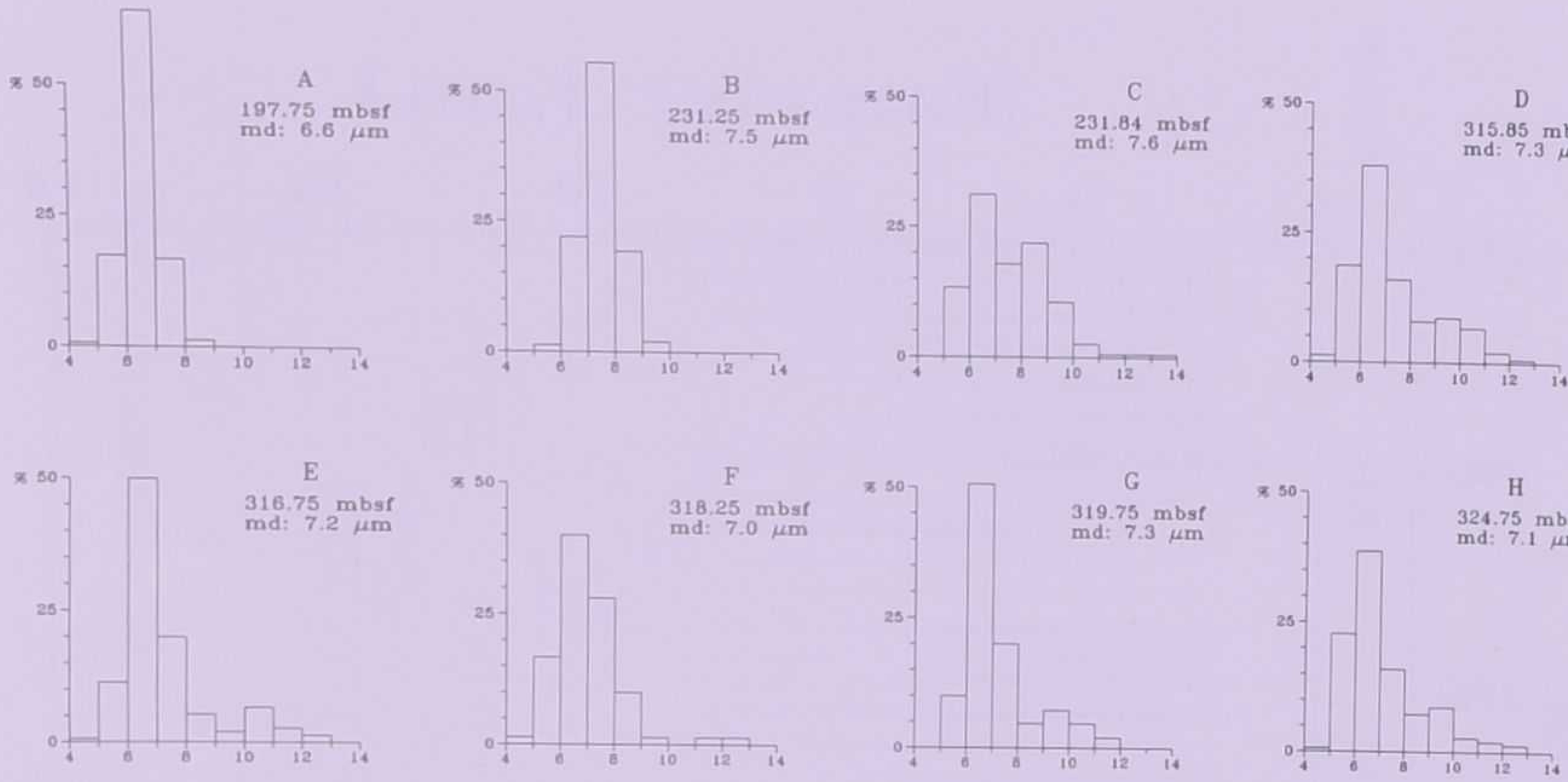

FIG. 4 - Histograms showing the size distribution of 150 specimens of *Cyclicargolithus* assemblage in selected samples from Hole 667A. The letters A through H refer to the position of the samples in Figure 3A.

In the interval where the morphotypes with a diameter >10 µm are continuously present, the histograms become right skewed but the majority of the specimens still have diameters ranging between 5 and 8 µm (Figs. 4c through 4h). The specimens which are >10 µm never exceed 10% of the *Cyclicargolithus* assemblage, and specimens >11 µm in diameter comprise generally less than 3%.

An attempt was made to find out if there is any relationship between the total abundance of *Cyclicargolithus* specimens and the size distribution within the group. The mean diameter of the *Cyclicargolithus* group is not affected by the abundance of *Cyclicargolithus* specimens relative to the total assemblage. Furthermore, no relationship was found between the abundance of *Cyclicargolithus* specimens and the abundance of the large forms (Tab. 3).

TABLE 3 - Correlation of the abundance (AB in specimens/mm²) of *Cyclicargolithus* specimens in ODP Hole 667A to mean diameter (MD in micrometers) of the assemblage, and the number of specimens within different size intervals in the assemblages

	Corr. coeff. (r)*
AB - MD	—0.05
AB - 8-9	0.03
AB - 9-10	0.07
AB - 10-11	0.04
AB - >11	0.11

* According to DAVIS, 1973.
r_{jk} = COV_{jk}/S_jS_k
COV = covariance = $(\Sigma_{i=i}^{n} X_{ij} X_{ik} - (\Sigma_{i=i}^{n} X_{ij} \Sigma_{i=i}^{n} X_{ik}/n))/n-1$
S = standard deviation.

FIG. 3 - A: Plot of the mean diameter of *Cyclicargolithus* assemblages in Hole 667A, where the mean value and 95% confidence intervals are shown. The letters A through H refer to the histograms in Figure 4.
B: Cumulative frequencies of *Cyclicargolithus* specimens with diameter > 9, 10 and 11 µm, respectively, in Hole 667A.
The stratigraphic positions of the Oligocene zonal boundaries in Hole 667A (Table 2) were estimated in the following way: The ages of the sphenolith events that define the Oligocene zonal boundaries (OKADA and BUKRY, 1980) were determined in DSDP Hole 522 (OLAFSSON and VILLA, in press) and then used to establish a timeframe for Hole 709C (FORNACIARI, *et al.*, 1990). Then the age of the first appearance (sharp rise in abundance) of *Triquetrorhabdulus carinatus* was determined in Hole 709C (210.5 ± 1.5 mbsf, 27.16 Ma) and used as a control point in Hole 667A (313.1 ± 1.9 mbsf). The zonal boundaries between the first appearance of *T. carinatus* and the last occurrence of *S. ciperoensis* were positioned by interpolation, while the zonal boundaries below the first appearance of *T. carinatus* were positioned with extrapolation.

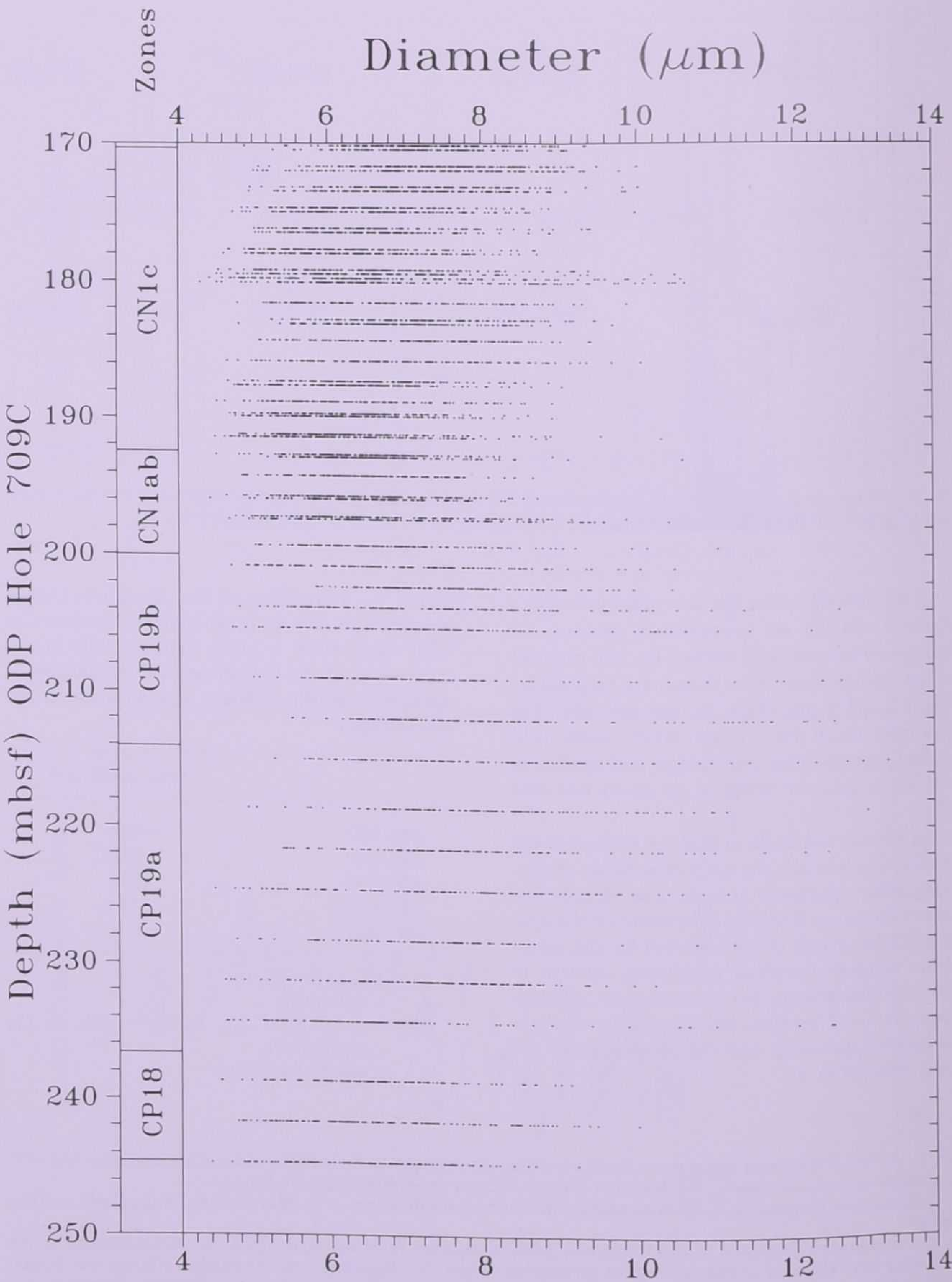

Fig. 5 - Scatter diagram where all the measured diameters are plotted against depth in Hole 709C.

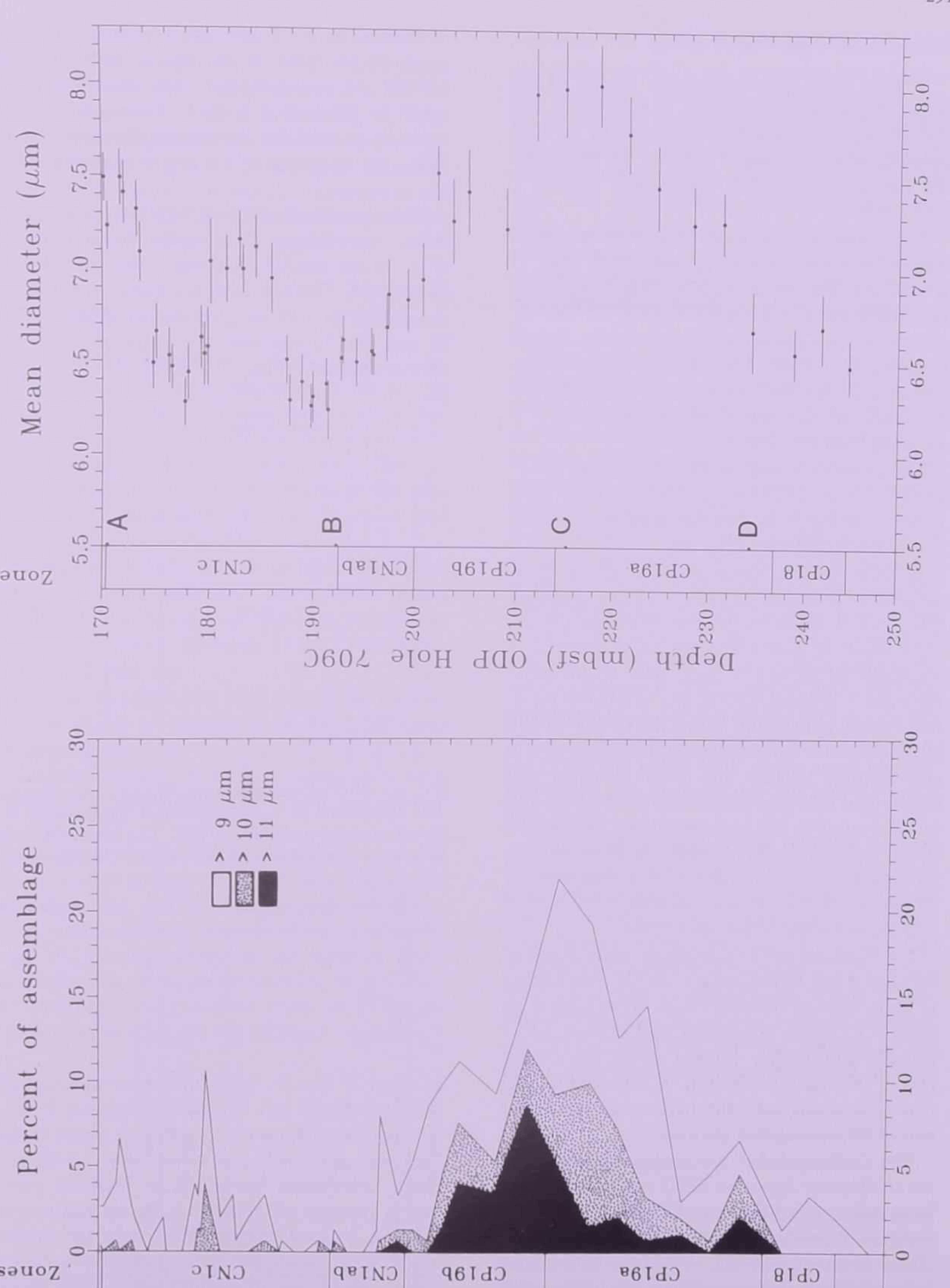

FIG. 6 - A: Plot of the mean diameter of *Cyclicargolithus* assemblages in Hole 709C, where the mean value and 95% confidence intervals are shown. The letters A through D refer to the histograms in Figure 7. The zonal boundaries are from (FORNACIARI, *et al.*, 1990). B: Cumulative frequencies of *Cyclicargolithus* specimens with diameter >9, 10 and 11 μm, respectively, in Hole 709C.

RESULTS FROM HOLE 709 C

In Hole 709C the stratigraphic control of the upper Oligocene is better than in Hole 667A, but the two sections can still be correlated by the first appearance of *T. carinatus* (246.5 ± 1.8 mbsf) and the last occurrence of *S. ciperoensis* (200.05 ± 0.75 mbsf).

The scatter diagram from Hole 709C where all measurements are plotted against depth (Fig. 5) is similar to the scatter diagram from the corresponding interval in Hole 667A (Fig. 2). The diameter of the *Cyclicargolithus* specimens ranges from 4.3 to 14.6 µm. The greatest spread of the diameter is observed around the CP19a/CP19b boundary, in the interval where the forms >11 are most abundant (Fig. 5).

The mean diamenter of *Cyclicargolithus* specimens in Zone CP18 through CN1c in Hole 709C is shown in Figure 6a together with the distribution of the large forms (Fig. 6b).

In Hole 709C the mean diameter of the *Cyclicargolithus* group ranges from 6.2 µm (Subzone CN1c, 191.4 mbsf) to 8.0 µm (Subzone CP19a, 218.6 mbsf). In Zone CP18, the mean diameter is relatively small, 6.5 – 6.7 µm. It increases throughout Subzone CP19a and reaches a maximum of 8.0 µm slightly below the CP19a/CP19b boundary at 218.6 mbsf. Through Subzone CP19b and Subzone CN1a-b the mean diameter decreases and reaches a minimum value of 6.2 µm at 191.4 mbsf in the lowermost part of Subzone CN1c. In Subzone CN1c the mean diameter varies between 6.2 and 7.5 µm, with a maximum of 7.1 µm at 182.8 mbsf and another maximum of 7.49 µm at the top of Subzone CN1c.

The *Cyclicargolithus* specimens with diameter between 9 and 10 µm have a similar distribution in Hole 709C as in Hole 667A. They appear at 246.2 ± 1.5 in the uppermost part of Zone CP17 and are continuously present up to the middle part of Subzone CN1a-b (Fig. 6). Above this level they occur sporadically throughout the remaining part of the investigated interval.

The *Cyclicargolithus* specimens that are 10-11 µm in diameter appear at 236.5 ± 2.2 mbsf in the lowermost part of Subzone CP19a and are continuously present up to 197.3 ± 0.1 mbsf in the middle part of Subzone CN1a-b. Throughout Subzone CN1c *Cyclicargolithus* specimens with diameter between 10 and 11 µm occur sporadically and in low abundances (Fig. 6).

The lowermost occurrence of specimens with diameters > 11 µm is at the same stratigraphic level as the first appearance of the specimens with diamter between 10 and 11 µm (Fig. 6).

Specimens > 11 µm are continuously present up to 203.8 mbsf in the upper part of Subzone CP19b and one specimen was observed at 199.3 mbsf in Subzone CN1a-b. Throughout the remaining part of the investigated interval in Hole 709C, no specimen > 11 µm was observed (Fig. 6).

The size distribution curves for the *Cyclicargolithus* assemblages in samples from Hole 709C (Fig. 7) are similar to those from samples from Hole 667A. The size distribution is normal where morphotypes > 10 µm are absent (Figures 7a and b) and the histograms are right skewed where they are present (Figs. 7c and d).

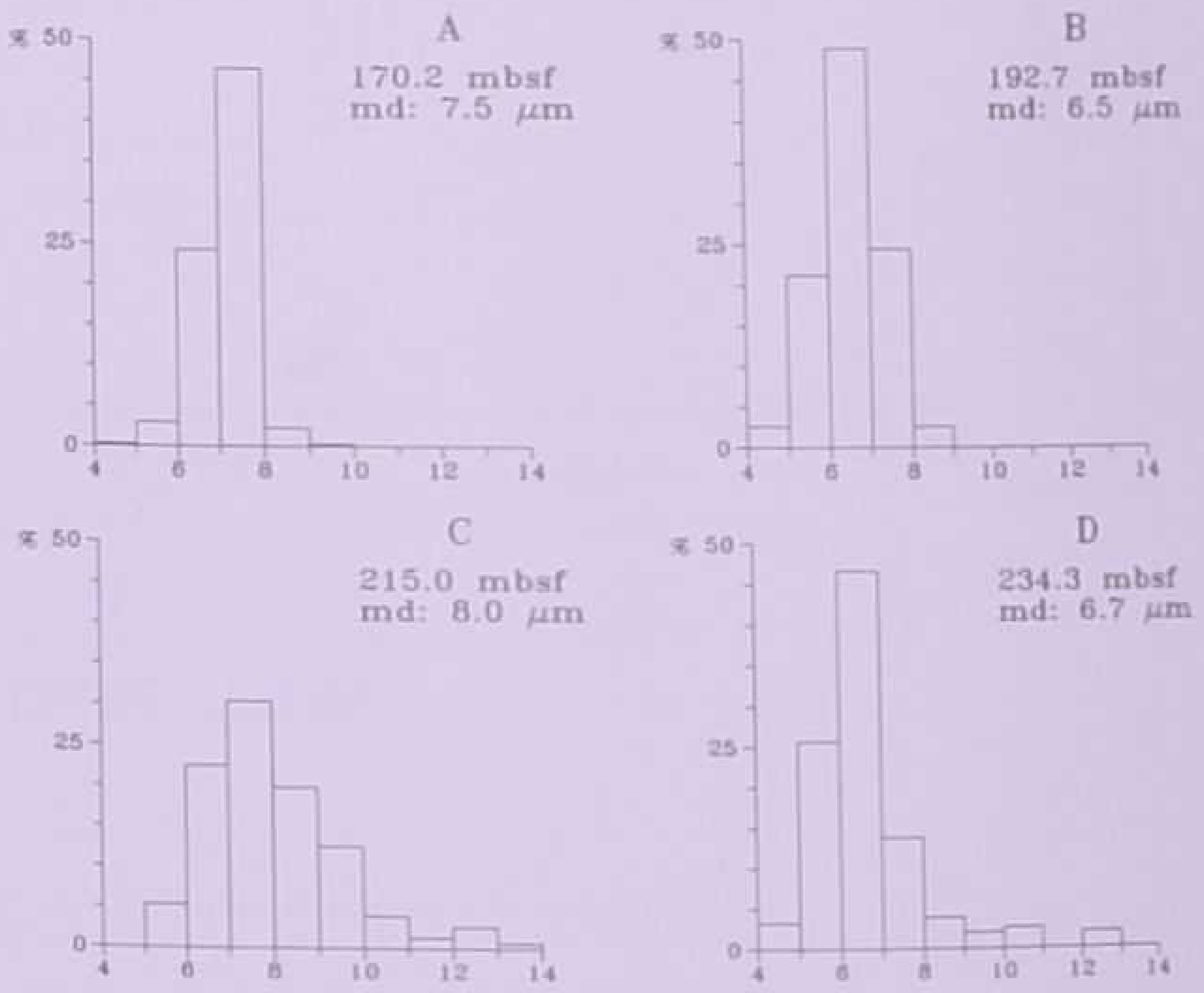

FIG. 7 - Histograms showing the size distribution of 150 specimens of *Cyclicargolithus* assemblage in selected samples from Hole 709C. The letters A through D refer to the position of the samples in Figure 6A.

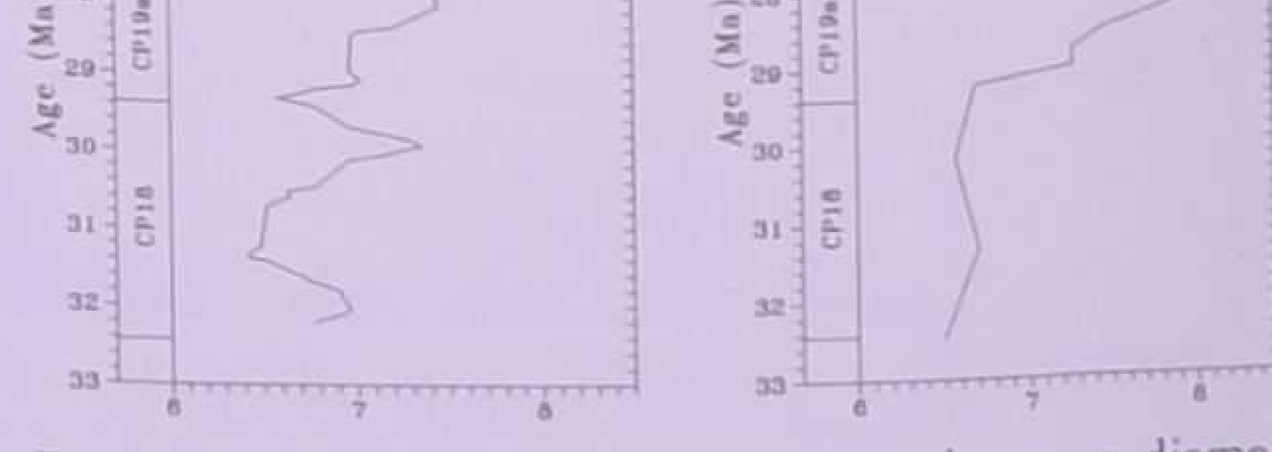

FIG. 8 - Comparison of the changes in the mean diameter of the *Cyclicargolithus* group in holes 667A and 709C. Because of the shorter sampling interval in Hole 667A, the mean diameter is plotted as a 5 point running mean. The nannofossil events used to define the zonal boundaries are summarized in Table 2 together with their depths and age estimates.

Despite the larger sampling interval used in Hole 709C, the variations of the mean diameter of the *Cyclicargolithus* group are similar as the variations observed in Hole 667A (Fig. 8). The greatest mean diameters are observed in the interval where the large forms are most abundant and an interval with low mean diameters is observed around the CN1b/CN1c boundary in both sections.

DISCUSSION

The mean diameter of a *Cyclicargolithus* assemblage at a given stratigraphic level in the equatorial Indian Ocean is somewhat greater than the mean diameter of an Atlantic Ocean assemblage from the same stratigraphic level. Despite this, the variations in the mean diameter are similar in both oceans through late Oligocene and early Miocene times (Fig. 8).

The size distribution within *Cyclicargolithus* assembages from different stratigraphic levels (Figs. 4 and 7) indicate that there are two factors that affect the mean diameter of the *Cyclicargolithus* group. These are:

1. Variation in specimen size within the smaller part (5 to 9 μm in diameter) of the assemblage (Figs. 4a and b).
2. Presence/absence of large morphotypes with diameters of approximately 10μm or greater (Figs. 4 and 7).

The variations of the specimen size within the *Cyclicargolithus* group could be caused by environmental factors such as change in the availability of nutrients, changes in surface temperature or change in salinity. Because no sections from higher latitudes were investigated with morphometric methods, a latitudinal effect could not be taken into consideration regarding the size variations.

The size distribution (Figs. 4 and 7) indicate that it is possible to regard the *Cyclicargolithus* group as being composed of two size groups. It is important to note, however, that these "groups" are not distinct in terms of bimodality. First, there is a size group A, where the majority of the members has diameters ranging between 5 and 9 μm. This group comprises the greater part of the *Cyclicargolithus* assemblage at any given stratigraphic level and is present throughout the whole interval studied, from Zone CP18 up to the lower part of Zone CN5. Second, there is a size group B, which is simply a large size fraction of the *Cyclicargolithus* population that has a limited stratigraphic distribution. Group B contains fewer members than group A and has a specimen size of approximately 11 μm or greater and is limited to the upper Oligocene. Where present, size group B causes the histogram of the size distribution to become right-skewed and it increases the mean diameter of the *Cyclicargolithus* assemblage. The shape of the size distribution curves (Figs. 4 and 7) indicate that the size distribution within the groups are independent of each other and the size variation within size group A is independent of the presence/absence of size group B.

If the boundary between the two size groups is arbitrarily drawn at a diameter of 10 μm then group B (>10 μm) occurs sporadically throughout the whole investigates interval (Figs. 3b and 6b). In Hole 709C the upper limit of the continuous presence of specimens >10 μm is in the interval assigned to Subzone CN1a-b but in Hole 667A it is at the CP19/CN1 boundary. This could be the same event that Bukry (1973, 1975) referred to as the "end of acme of *Cyclicargolithus abisectus*" and used to define the CN1a/CN1b boundary. Because of the different ranges of specimens >10 μm and the sporadic occurrence throughout the investigated interval it is not feasible to use a diameter of 10 μm as the boundary between the two size groups A and B. Furthermore, it is not possible to use the upper limit of the range of specimens >10 μm to mark the CN1a/CN1b boundary.

On the other hand, if the boundary between the two size groups is drawn at a diameter of 11 μm, then size group B has a stratigraphic range that is limited to Zone CP19 in the upper Oligocene. In both holes, size group B (>11 μm) appears at the CP18/CP19 boundary and is continuously present up to the uppermost part of Subzone CP19b (Figs. 3b and 6b). Sporadic occurrences of specimens >11 μm are observed in the upper part of the investigated interval in Hole 667A.

CONCLUSIONS

Based on differences in size, the *Cyclicargolithus* group from upper Oligocene and lower Miocene can be divided into two size groups, A and B. The majority of the members of group A has diameters ranging between 5 and 9 μm, never exceeding 11 μm. This size group is present throughout the whole investigated interval (CP18-CN5) and comprises the main body of the *Cyclicargolithus* assemblage at any given stratigraphic level. The other size group (B) has members with diameters greater than 11 µm. It is useful as a biostratigraphic marker in equatorial regions since it has a stratigraphical range limited to the upper Oligocene (CP19). The *Cyclicargolithus* group in the equatorial Atlantic Ocean shows similar variations in the mean diameter as the *Cyclicargolithus* group in the equatorial Indian Ocean. The mean diameter can be said to be affected by two factors: First, the mean diameter of size group A varies, which in turn explains the variations observed where size group B is absent. Second, the presence of size group B increases the mean diameter of the *Cyclicargolithus* assemblage without affecting the size distribution within size group A.

The similar variations in the mean diameter of size group A, that are observed in both regions, indicate similar changes in the environmental conditions throughout late Oligocene and into early Miocene times.

The presence of the two *Cyclicargolithus* size groups in equatorial regions indicate that difference in specimen size can be used as a criterion to distinguish between *C. abisectus* and *C. floridanus*. If the limit between the two size groups is set at a diameter of 11 µm, then, size group A could be assigned to *C. floridanus* and size group B to *C. abisectus*. Before this is done and a formal recombination of the *Cyclicargolithus* group is made, further investigations on *Cyclicargolithus* assemblages, especially from different latitudes, are needed.

Finally, the use of the "end of acme of *C. abisectus*" to mark the CN1a/CN1b boundary should be abandoned. Instead Zone CN1 should be divided into Subzone CN1a, ranging from the last occurrence of *Sphenolithus ciperoensis* to the first appearance of *Discoaster druggii*, and Subzone CN1b ranging from the first appearance of *D. druggii* to the first appearance of *Sphenolithus belemnos*.

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