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17. MORPHOMETRIC CHANGES OF THE GENUS *GEPHYROCAPSA* AT SITE 790, SUBTROPICAL PACIFIC OCEAN[1]

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ABSTRACT

Cyclic changes in the morphometry of large specimens of the calcareous nannofossil genus *Gephyrocapsa,* first discovered in the Indian Ocean, are recognized in the middle Quaternary sedimentary sequence of Site 790 drilled in the Izu-Bonin forearc. The second and a part of the third cycle of morphometric development of large *Gephyrocapsa* were identified at this site. Small *Gephyrocapsa* (in particular, *Gephyrocapsa protohuxleyi* var. A and *Gephyrocapsa ornata* var. A) generally compose approximately 50% of the middle Quaternary nannoflora. Four abundance peaks of the small *Gephyrocapsa* complex were seen in this middle Quaternary sequence, three of which were not seen in previously studied Indian Ocean or Mariana Arc cores.

INTRODUCTION

Matsuoka and Okada (1989) studied morphometric changes of the calcareous nannofossil genus *Gephyrocapsa* in subtropical Pacific Ocean Core KH84-1 st. 21 (Fig. 1). They recognized significant variations in the morphometry of *Gephyrocapsa* during the last 1.3 m.y. and a prominent acme of *Gephyrocapsa protohuxleyi* var. A near the Brunhes/Matuyama boundary. Matsuoka and Okada (1990) also reported morphometric changes of the genus *Gephyrocapsa* in the Quaternary sequence cored at Site 709 in the equatorial Indian Ocean. They identified three development cycles of the large morphotype of *Gephyrocapsa* (1.6–1.1, 0.9–0.5, and 0.5 Ma to the present). The large morphotype of *Gephyrocapsa* was approximately 3 µm in diameter during the early stage of each cycle and increased in size through the latter part of each cycle. The morphotypes disappeared rapidly at the end of the earlier two cycles. The prominent acme of *G. protohuxleyi* var. A was also observed at Site 709.

The coccoliths examined in the Quaternary sedimentary sequence recovered at Site 790 in the Izu-Bonin Arc region display good preservation characteristics. We studied this Quaternary sequence to determine the temporal and spatial differences of morphometric changes of *Gephyrocapsa* between the tropical Indian Ocean and the Izu-Bonin Arc.

MATERIALS AND METHODS

Site 790 is located at the center of Sumisu Rift (30°54.95′N, 139°50.69′E, water depth of 2223.5 m below sea level [mbsl]) in the Izu-Bonin Arc (Fig 1). The upper Quaternary portion of the section consists of volcaniclastic sediments and thus was not suitable for this morphometric study. The middle Quaternary sedimentary sequence, however, consists of nannofossil-rich clays. Two datum events were identified in this middle Quaternary sequence (Fig. 2): (1) the last occurrence (LO) of *Pseudoemiliania lacunosa,* located between Sections 126-790C-15X-CC and -16X-1, 40–41 cm; and (2) the LO of *Reticulofenestra* sp. A, located between Cores 126-790C-18X and -19X (Shipboard Scientific Party, 1990). These events also are present at Site 709 in the Indian Ocean and at Site KH84-1 st. 21 in the Mariana Arc, providing correlatable stratigraphic horizons for spatial comparisons with samples from this study. We selected a set of 20 samples from Cores 126-790C-16X through -19X and observed them under a transmission electron microscope to investigate the morphometric variations of *Gephyrocapsa* (Table 1).

The first 200 specimens of *Gephyrocapsa* identified in each sample were measured for overall size, diameter of the central opening, and angle of the central bridge relative to the long axis of the coccolith. The length and width axes were measured to within 0.1 µm. The bridge angle is difficult to measure precisely under a transmission microscope; thus, it was classified into one of three broad categories: 0°–30°, 30°–60°, and 60°–90°. For samples in which the small forms were dominant, measurements were made on 100 additional larger specimens to obtain a sufficiently large *Gephyrocapsa* data set. We also determined the composition of the nannoflora, excluding *Florisphaera profunda,* by identifying the first 350 coccoliths encountered.

RESULTS AND DISCUSSION

Classification of *Gephyrocapsa*

The classification of *Gephyrocapsa* in this study closely follows the one proposed by Matsuoka and Okada (1990). They identified two groups of *Gephyrocapsa:* small *Gephyrocapsa,* which consist of small specimens with relatively large central openings; and large *Gephyrocapsa,* which consist of large specimens with relatively small central openings. In this study, plots of the overall coccolith size vs. the diameter of the central opening were used to identify each group (Fig. 3).

Matsuoka and Okada (1990) further divided the large *Gephyrocapsa* into four subspecies (*Gephyrocapsa* sp. A, *Gephyrocapsa* sp. B, *Gephyrocapsa* sp. C, and *Gephyrocapsa* sp. D). The two latter species were identified in samples examined in this study. Large *Gephyrocapsa* specimens identified in the interval from 228.1 to 255.5 mbsf (Samples 126-790C-16X-4, 80–81 cm, through -19X-3, 80–81 cm) are characterized by high-angle (>60°) bridges and were classified as *Gephyrocapsa* sp. C. *Gephyrocapsa* sp. D, characterized by a low-angle bridge, were identified in the interval from 223.6 to 229.6 mbsf (Samples 126-790C-16X-1, 80–81 cm, through -16X-5, 80–81 cm).

Only two taxa, *Gephyrocapsa protohuxleyi* var. A with slits on the distal shield and *Gephyrocapsa* spp. (small) without slits on the distal shield, were recognized in the small *Gephyrocapsa* complex by Matsuoka and Okada (1990). In addition to these two taxa, *Gephyrocapsa ornata* var. A was abundant in samples examined in this study. *G. ornata* var. A is larger than the type species (an average length of 2.9 µm); it has moderate protrusions, a high archlike bridge, and tooth-shaped protrusions around the central opening. This variety is restricted temporally to the middle Quaternary. *Gephyrocapsa ornata* var. A was further subdivided into two morphotypes: one with slits on its distal shield and the other without slits.

Heimdal's (1973) classification noted the presence of specimens similar to the type of *G. ornata* var. A that do not have a bridge.

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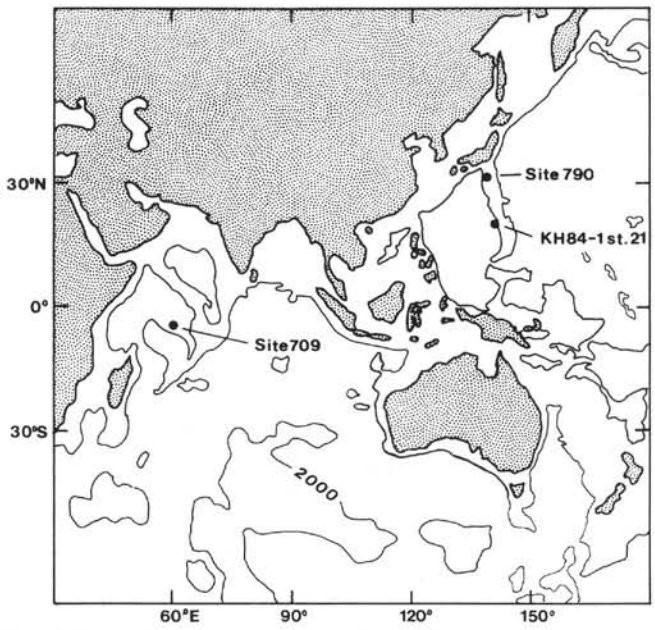

Figure 1. Location map of Sites 709, 790, and KH84-1 st. 21.

Specimens similar to those described by Heimdal were observed from 244.40 to 247.48 mbsf (Samples 126-790C-18X-2, 80–81 cm, through -18X-4, 88–89 cm). These specimens, classified as *Reticulofenestra parvula* var. A. in this study, are smaller than *G. ornata* var. A (2.4 μm); they have tooth-shaped protrusions instead of a collar and a more robust grid that spans the central opening.

Morphometric Changes in Large *Gephyrocapsa*

The morphometric variations of the large *Gephyrocapsa* examined in this study are generally consistent with those observed at Site 709 in the equatorial Indian Ocean. As noted above, two intervals of morphometric development were recognized during the middle Quaternary: one dominated by *Gephyrocapsa* sp. C (228.1–255.5 mbsf) and another dominated by *Gephyrocapsa* sp. D (223.6–229.6 mbsf).

Although the general trends of morphometric change in large *Gephyrocapsa* in Sites 709 and 790 are similar, several differences were noted. The average coccolith size of *Gephyrocapsa* sp. C is slightly larger and the size of the central opening is more variable in specimens from Site 790 than those from Site 709 (Fig. 4). Over the interval examined, the average size of *Gephyrocapsa* sp. C increases from 3.8 to 4.7 μm at Site 790, and from 3.5 to 4.2 μm at Site 709. The difference in average size of *Gephyrocapsa* sp. C between Sites 790 and 709 is 0.2 μm at the LO of *Reticulofenestra* sp. A (0.83 Ma). The small decrease in the size of *Gephyrocapsa* sp. C between 230 and 235 mbsf at Site 790 is not seen at a similar stratigraphic horizon at Site 709. In the Indian Ocean, the abundance of *Gephyrocapsa* sp. C decreases with an increase in overall size. This trend is not recognized in samples from the Izu-Bonin Arc (Fig. 5). This difference, however, may be an artifact of an increase in the abundance of small *Gephyrocapsa* at Site 709.

Abundance Patterns of Small *Gephyrocapsa*

The abundance pattern of small *Gephyrocapsa* at Site 790 differs significantly from that at Site 709. Small *Gephyrocapsa* (in particular, *Gephyrocapsa protohuxleyi* var. A and *Gephyrocapsa ornata* var. A) compose approximately 50% of the nannoflora in the middle Quaternary sequence of Hole 790C (Fig. 6). Short intervals characterized by peaks in abundance of small *Gephyrocapsa* are seen at 260.0 mbsf

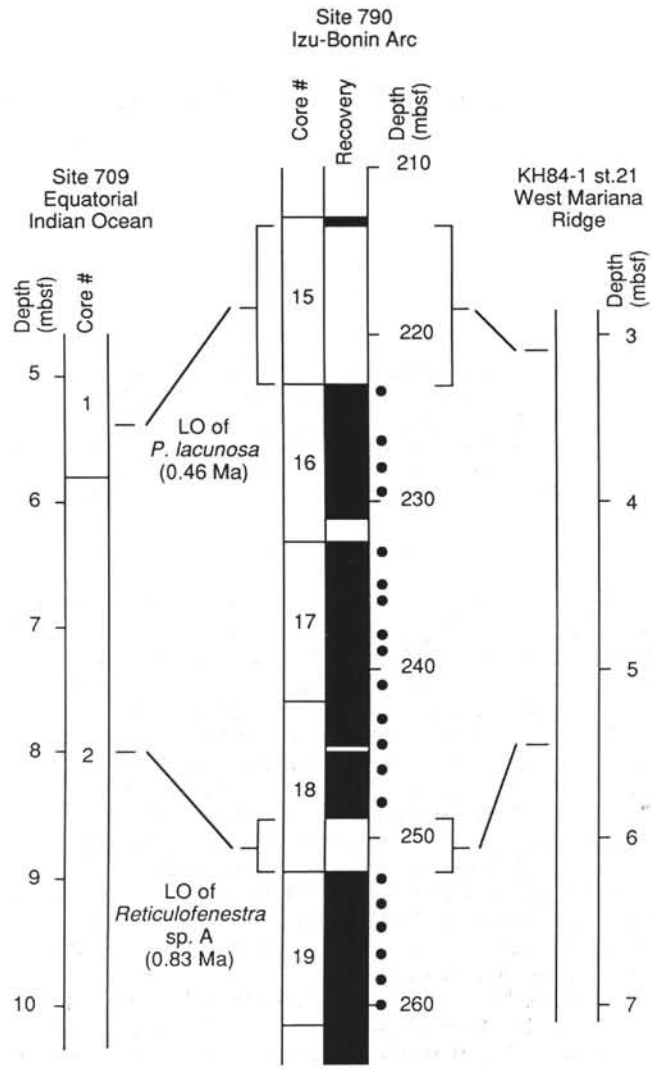

Figure 2. Biostratigraphic relationships among Sites 709, 790, and KH84-1 st. 21. Solid circles represent sampling horizon at Site 790. LO = last occurrence.

(Sample 126-790C-19X-6, 80–81 cm), 242.9 mbsf (Sample 126-790C-18X-1, 80–81 cm), and 234.72 mbsf (Sample 126-790C-17X-2, 82–83 cm) and are labeled Dominance Intervals I, III, and IV, respectively on Figure 6. Except for the third abundance peak, these dominance intervals were not recognized in either Site 709 or Core KH84-1 st. 21.

In Dominance Interval I, *G. protohuxleyi* var. A., which is characterized by a relatively small overall size (2.3 μm), is the predominant taxon. In Dominance Interval II (247.48 mbsf), *Reticulofenestra parvula* var. A is the predominant taxon. Although this form does not belong to "*Gephyrocapsa*," it displays an abundance pattern similar to that of *Gephyrocapsa*.

Dominance Interval III differs from the other intervals by the abundant co-occurrence of *G. protohuxleyi* var. A and *Gephyrocapsa* spp. (small). Specimens of *G. protohuxleyi* var. A in this sequence are larger (2.9 μm) and have a more rugged edge around the shield than specimens in the other intervals. Many specimens of *Gephyrocapsa* spp. (small) are morphometrically similar to that of *G. protohuxleyi* var. A except for the absence of slits on the shield; these specimens are probably a morphotype of *G. protohuxleyi* var. A. This dominance interval correlates with the acme of *G. protohuxleyi* var. A in the Mariana core (KH82-4 st. 21) documented by Matsuoka and Okada (1989).

Table 1. List of samples studied.

Core, section, interval (cm)	Depth (mbsf)
126-790C-	
16 X-1, 80-81	223.60
16 X-3, 80-81	226.60
16 X-4, 80-81	228.10
16 X-5, 80-81	229.60
17 X-1, 80-81	233.20
17 X-2, 82-83	234.72
17 X-3, 80-81	236.20
17 X-4, 85-85	237.75
17 X-5, 80-81	239.20
17 X-6, 80-81	240.70
18 X-1, 80-81	242.90
18 X-2, 80-81	244.40
18 X-3, 80-81	245.90
18 X-4, 88-89	247.48
19 X-1, 80-81	252.50
19 X-2, 80-81	254.00
19 X-3, 80-81	255.50
19 X-4, 80-81	257.00
19 X-5, 80-81	258.50
19 X-6, 80-81	260.00

Dominance Interval IV is characterized by abundant *G. ornata* var. A. *Gephyrocapsa ornata* var. A without slits is abundant from 233.20 to 237.75 mbsf (Samples 126-790C-17X-1, 80–81 cm, through -17X-4, 85–85 cm), whereas *G. ornata* var. A with slits is the predominant taxon at 234.72 mbsf (Sample 126-790C-17X-2, 82–83 cm).

Gartner's (1977) zonal scheme documented abundance peaks of small *Gephyrocapsa* in the middle Quaternary and named the interval "small *Gephyrocapsa* Zone." This zone is characterized by an abundance of small *Gephyrocapsa* with high-angle bridges (>60°) and small size (1.7–2.0 µm). This zone is different from the four dominance intervals recognized in this investigation. First, the "small *Gephyrocapsa* Zone" occurs at about 1.1–0.9 Ma and is older, therefore, than the four abundance peaks recognized in this paper (about 0.9–0.5 Ma). Second, *G. protohuxleyi,* present in samples examined in this study, is generally absent in the "small *Gephyrocapsa* Zone" at Site 709. Further investigations are required to document additional differences between the "small *Gephyrocapsa* zone" and the dominance intervals identified in this study as well as to understand the paleoceanographic implications of these differences.

Gephyrocapsa protohuxleyi var. A, *G ornata* var. A, and *R. parvula* var. A, which compose the four dominance intervals, show large morphometric variations. *Gephyrocapsa ornata* var. A has four morphotypes: one with slits on the distal shield and a bridge in the central opening, another without slits and with a bridge, a third with a slit and without a bridge, and a fourth without slits or a bridge. These morphotypes are similar to *Gephyrocapsa protohuxleyi, Gephyrocapsa ericsonii, Emiliania huxleyi*, and *Reticulofenestra parvula*, respectively.

Heimdal (1973) also noted that *G. ornata* is closely related to *G. ericsonii* and *G. protohuxleyi.* Living *G. protohuxleyi* were found with *G. ericsonii* and *E. huxleyi* in the Gulf of Elat (Winter et al., 1978). Winter (1982) reported abundant occurrences of *G. ericsonii* and *G. ornata* in Isotope Stages 5 and 4, respectively, of the piston core sediments in the Gulf of Elat. Biekart (1989) reported the prominent occurrence of *Florisphaera profunda, Dictyococcites sessilis, Reticulofenestra parvula, Gephyrocapsa* sp. aff. *G. ericsonii,* and *Reticulofenestra minuta* in piston core sediments of southeast Indonesian basins. From their characteristic morphometry and co- occurrences, we think that *G. protohuxleyi* var. A, *G. ornata* var. A, and *R. parvula* var. A represent morphotypes of one taxon.

SUMMARY

The patterns of morphologic change of the large *Gephyrocapsa* in middle Quaternary sediments from Site 790 are generally coincident with those of Indian Ocean Site 709. The second and a part of the third cycle of morphometric development of the large *Gephyrocapsa* were recognized in the middle Quaternary sedimentary sequence in Site 790. The average size of *Gephyrocapsa* sp. C at Site 790 is slightly larger (0.2–0.5 µm) than at Site 709.

Four abundance peaks of small *Gephyrocapsa* and *Reticulofenestra* (*G. protohuxleyi* var. A, *G. ornata* var. A, and *R. parvula* var. A) were observed in the middle Quaternary sequence at Site 790. Except for the third abundance peak, these dominance intervals were not observed in either the Indian Ocean or the Marianas.

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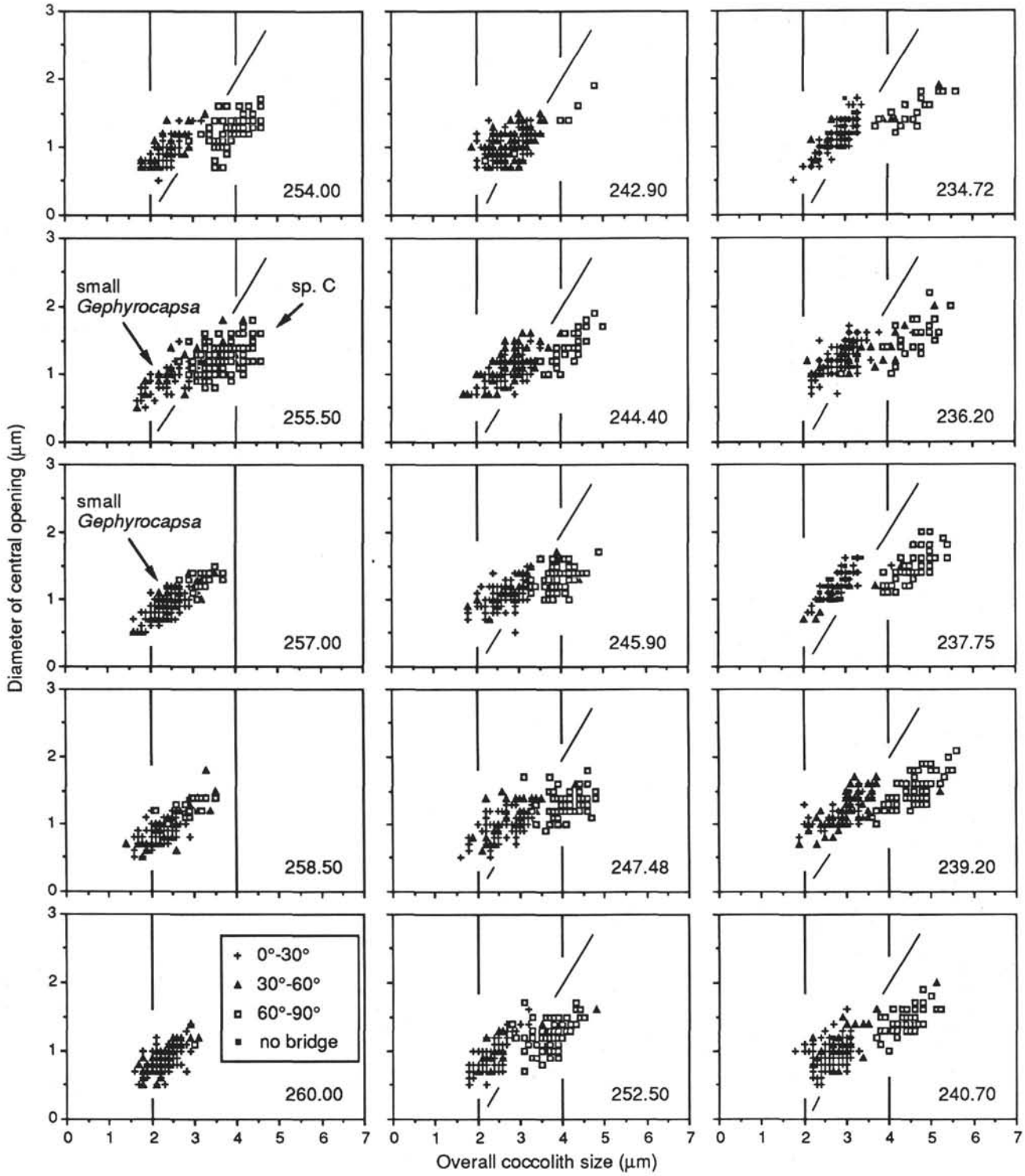

Figure 3. Plot of overall coccolith size (horizontal axis) vs. diameter of central opening (vertical axis) for the first 200 specimens of *Gephyrocapsa* observed in the samples studied. Numerical values in the lower right corner of each plot indicate sub-bottom depth (expressed in mbsf) of each sample. The horizontal and vertical scales are expressed in microns. The diagonal line indicates the boundary between small and large *Gephyrocapsa.* The four categories of the bridge angle (30° intervals) that denotes the inclination of bridge vs. the long axis of coccolith are represented as follows: plus signs = specimens with low bridge angles (0°–30°), solid triangles = specimens with medium (30°–60°) bridge angles, open squares = specimens with high (60°–90°) bridge angles, and small solid squares = specimens without a bridge.

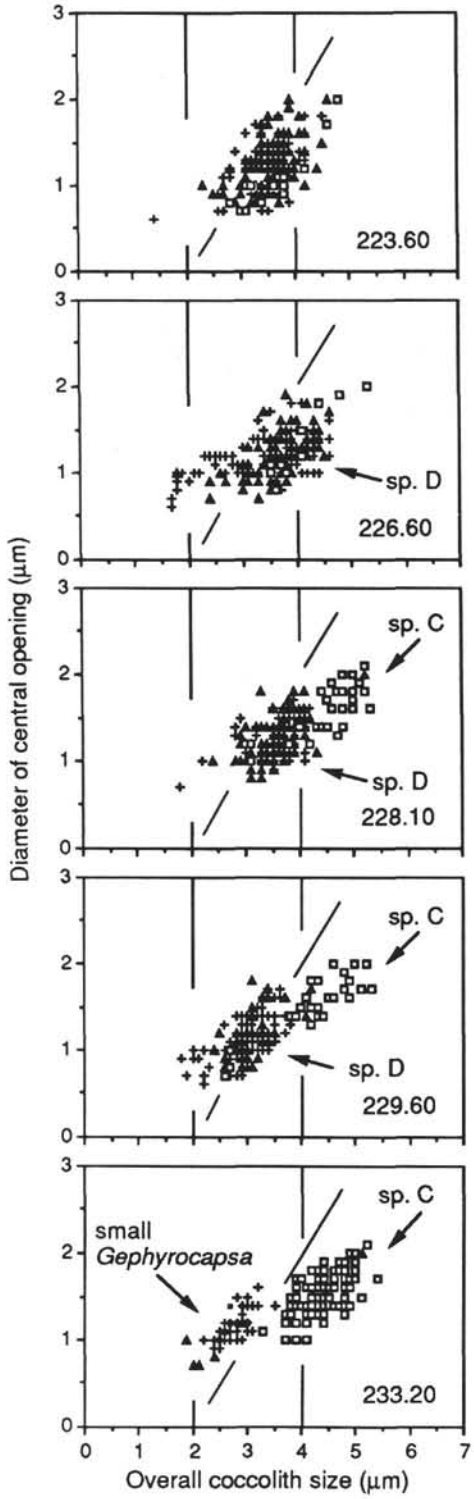

Figure 3 (continued).

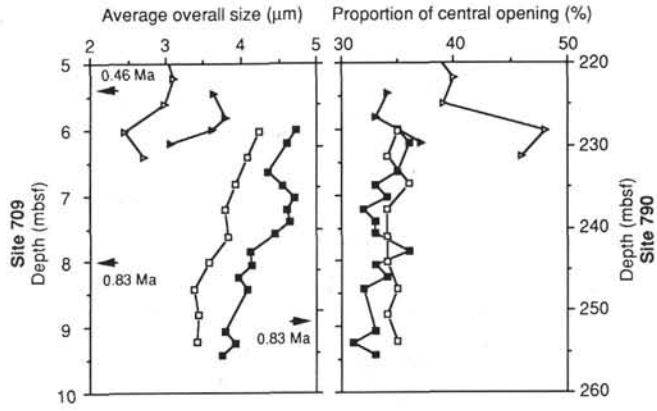

Figure 4. Stratigraphic changes in the average coccolith size (left column) and the averaged proportion of the central openings (right column) of *Gephyrocapsa* sp. C and *Gephyrocapsa* sp. D at Sites 709 and 790. Samples in which large *Gephyrocapsa* are exceedingly scarce were omitted in this figure. Open squares = Site 709 *Gephyrocapsa* sp. C, open triangles = Site 709 *Gephyrocapsa* sp. D, solid squares = Site 790 *Gephyrocapsa* sp. C, and closed triangles = Site 790 *Gephyrocapsa* sp. D.

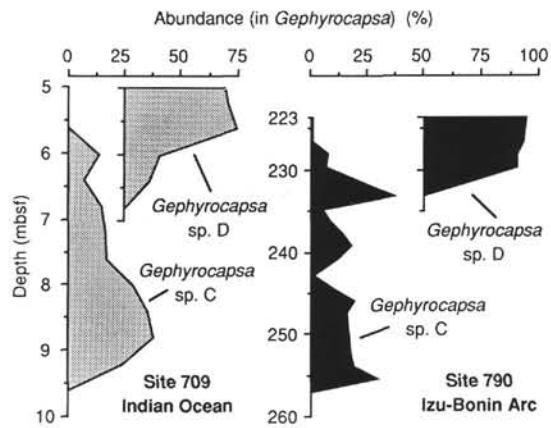

Figure 5. Stratigraphic changes in percentage occurrence of *Gephyrocapsa* sp. C and *Gephyrocapsa* sp. D at Sites 709 and 790. The percentage abundance indicates the value within *Gephyrocapsa*.

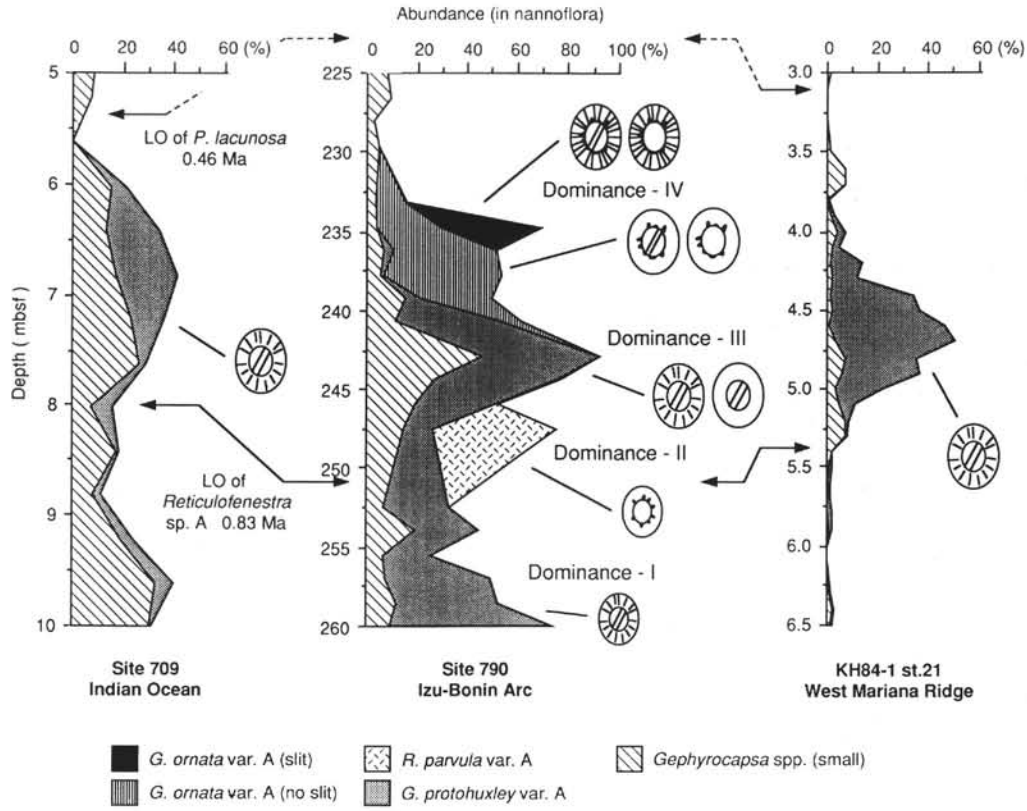

Figure 6. Stratigraphic occurrences in the abundance of small *Gephyrocapsa* at Sites 709 and 790. Data are expressed as percentage abundances within the total nannoflora.

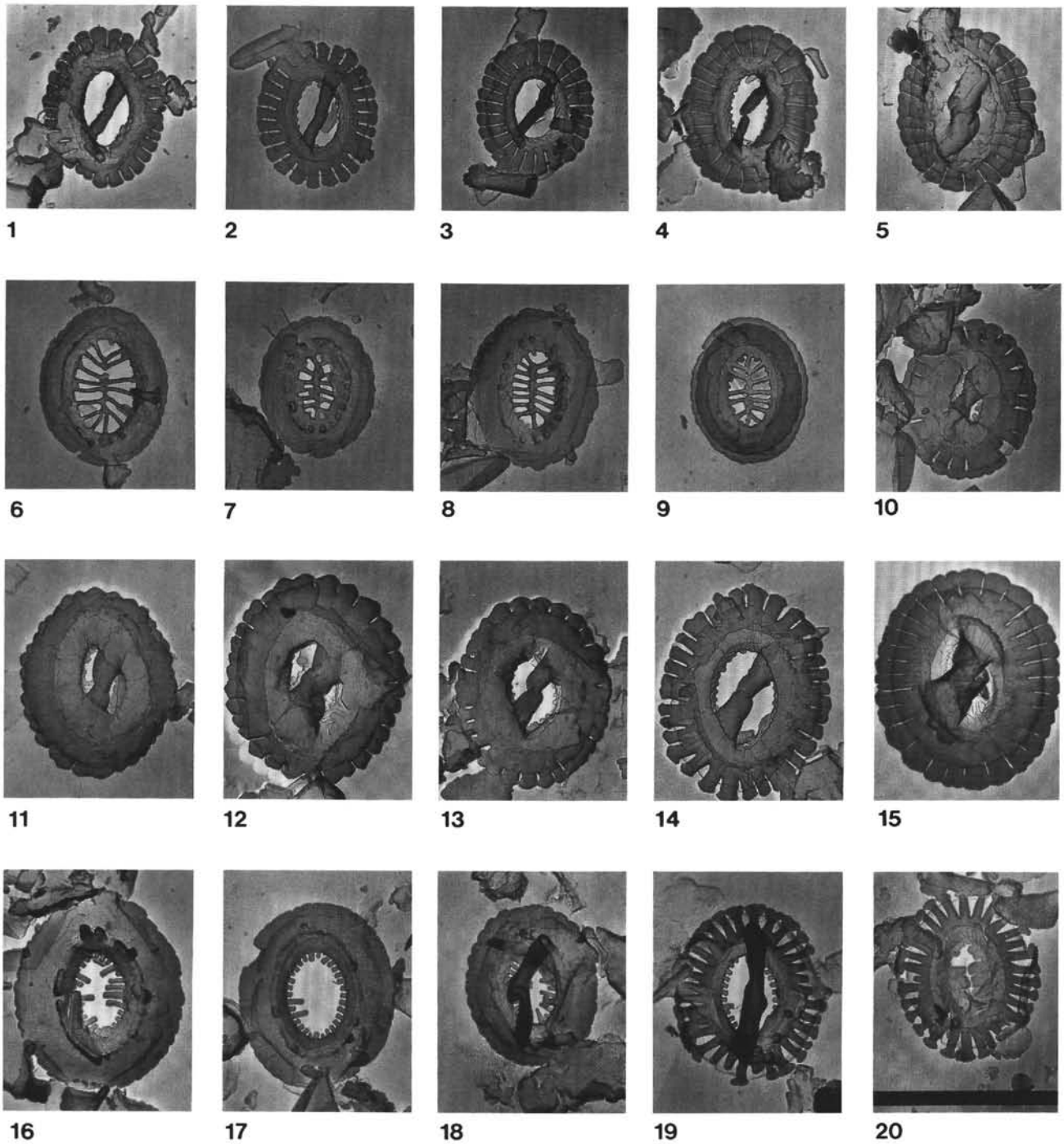

Plate 1. Transmission electron microscope micrographs. All figures are same magnification (×10,000). Scale bar in Figure 20 represents 3 µm. **1–5.** *Gephyrocapsa protohuxleyi* var. A; (1) Sample 126-790C-19X-6, 80–81 cm (260.00 mbsf); (2) Sample 126-790C-19X-5, 80–81 cm (258.50 mbsf); (3–4) Sample 126-790C-19X-4, 80–81 cm (257.00 mbsf); (5) Sample 126-790C-19X-1, 80–81 cm (252.50 mbsf). **6–9.** *Reticulofenestra parvula* var. A, Sample 126-790C-18X-4, 88–89 cm (247.48 mbsf). **10–15.** *Gephyrocapsa protohuxleyi* var. A; (10) Sample 126-790C-18X-3, 80–81 cm (245.90 mbsf); (11–14) Sample 126-790C-18X-1, 80–81 cm (242.90 mbsf); (15) Sample 126-790C-17X-5, 80–81 cm (239.20 mbsf). **16–20.** *Gephyrocapsa ornata* var. A; (16) Sample 126-790C-17X-4, 85–85 cm (237.75 mbsf); (17–20) Sample 126-790C-17X-2, 82–83 cm (234.72 mbsf).