

### 13. NANNOFOSSILS FROM QUATERNARY DEPOSITS IN THE HIGH-PRODUCTIVITY AREA OF THE CENTRAL EQUATORIAL PACIFIC, DEEP SEA DRILLING PROJECT LEG 85<sup>1</sup>

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#### ABSTRACT

During Leg 85, drilling was undertaken at DSDP Sites 571 to 575 in the high-productivity area of the central equatorial Pacific. Nannofossil-rich Quaternary sediment was recovered at the five sites, and provided adequate material for a detailed study of coccoliths. Various species and variants were found; the most important of them are briefly described and are used for a precise determination of stratigraphy. Besides conventional datums, some additional markers (*Gephyrocapsa ericsonii*, *Gephyrocapsa oceanica* s. s., *Gephyrocapsa doronicoides* s. ampl., *Crenalithus productus*, *Cyclococcolithina* sp. cf. *C. macintyreii*, *Coccolithus pelagicus*) proved useful for correlating sites and for correlating Leg 85 sites with other Quaternary sections. In addition, nannofossil total abundance is often close to CaCO<sub>3</sub> content, and so can be used for locating carbonate cycles; carbonate cycles represent a standard stratigraphic tool in the equatorial Pacific. Finally, carbonate dissolution is commonly strong in this area. In the most dissolved samples, the almost exclusive presence of reworked coccoliths might be explained by the episodic influence of a corrosive water mass (possibly a deep current from Antarctica).

#### INTRODUCTION

The central equatorial Pacific is well known as an area of high biologic productivity. Siliceous (diatoms, radiolarians, silicoflagellates) and calcareous (foraminifers and nannofossils) organisms are very abundant, generally in the same samples, and they commonly show good preservation. In spite of the great importance of this productive area, very few Quaternary high-resolution studies have been published. Hays et al. (1969) studied planktonic foraminifers and radiolarians in various short cores with a low rate of sedimentation, from the equatorial Pacific; the carbonate curve of Core RC 11-209 (with cycles named after Arrhenius's results [1952]) is considered now to be a standard record of the Pacific. Shackleton and Opdyke (1973, 1976) gave oxygen-isotope measurements from two cores of the western tropical Pacific, which are standard records for isotopes. DSDP Site 77 of Leg 9 (Bukry, 1972; Hays et al., 1972) is considered a reference for the equatorial Pacific, but Quaternary sediments at this site were disturbed by rotary drilling.

Quaternary nannofossils were even less studied. Okada and Honjo (1973) and Geitzenauer et al. (1977) described Recent nannoplankton of most of the Pacific, with ecologic and nomenclatural objectives. On Leg 68, Rio (1982) made a detailed study of Quaternary nannofossils of DSDP Site 503, in the Panama Basin. In this study, Rio did not use some important taxa (especially the group of *Gephyrocapsa caribbeanica*, *Gephyrocapsa doronicoides*, some small *Gephyrocapsa*, etc.), so that comparison with Italian sections has to be confirmed. Finally, radiolarians and nannofossils permit dating of

an upper Quaternary section cored close to DSDP Site 77 (Labracherie et al., 1981).

On Leg 85, coring was conducted at five sites along two transects (east-west and south-north) across the northern part of the equatorial high-productivity area (Fig. 1). All sites proved to have reasonably abundant Quaternary nannofossils (site chapters, this volume). These sections are of interest because of their medium to high carbonate contents, their high rates of sediment accumulation, without big gaps, and their apparently undisturbed character. Such material is appropriate for a study of Quaternary nannofossils that tries to establish a high-resolution stratigraphy for this area.

#### METHODS

All the Quaternary sections were sampled in detail, usually each 20 or 40 cm; at DSDP Site 575, the study on board showed that the sediment accumulation rate was very low, and cores from this site were sampled each 10 cm.

For most of the work, I used smear slides, studied with a light microscope at a magnification of 1200×. Some samples were studied with a scanning electron microscope (SEM) to identify and study details of morphology of the smallest coccoliths; but generally the use of the light microscope was sufficient.

To evaluate the nannofossil total and specific abundances on smear slides, a semiquantitative method, fairly close to that described by Backman and Shackleton (1983, p. 146: first mean), was used. In the present work I used equal quantities of sediments for the smear slides, so that nannofossil abundances are comparable for all the samples. Total abundances were estimated on one field of view, using the same magnification (1200×). Fairly abundant or very abundant species were roughly counted or estimated in a semiquantitative way, on ten fields of view, using the count scale drawn on Figures 2 to 9. For rare species, specimens were counted exactly, always on ten fields of view. In using this method (equivalent-sized sediments; equal number of fields of view at the same magnification), I obtained absolute data which proved to be "surprisingly accurate...from slides made by a single experienced worker. [The method]...represents a fast and highly accurate way to gather biostratigraphic information" (Backman and Shackleton, 1983).

In addition, for two holes (572A and 573), the CaCO<sub>3</sub> content of the bulk sediment was measured in the same samples that were used in the study of nannofossils. Percent CaCO<sub>3</sub> was determined with a Bernard calcimeter (method described in Vatan, 1967). The carbonate content at Site 571 was measured on board (see site chapter).

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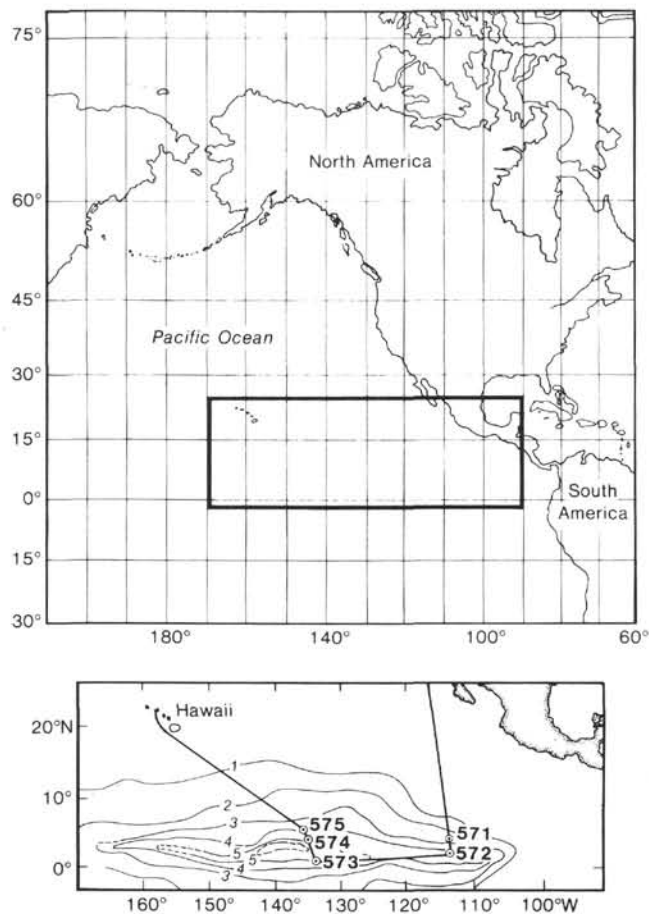


Figure 1. Locations of Leg 85 sites in relation to sediment thickness (contours in tenths of seconds of two-way traveltime). *Glomar Challenger* course to Hawaii is shown in inset, indicated on main figure by bold outline.

### PRESERVATION

The preservation of nannofossils varies strongly in the Quaternary material. In many samples, the composition of nannofossil associations seems not to be disturbed by dissolution, and coccoliths are abundant. But even in these associations, dissolution is obvious. In a few samples, the  $\text{CaCO}_3$  content is low, and some species are lacking, especially those which are not solution-resistant (Berger, 1973a, b, c). In samples with a minimum of  $\text{CaCO}_3$ , almost all the coccoliths are dissolved, and only some "ghosts" can be seen. This gradient of dissolution is given with more accuracy by a "solution index" (Bukry, 1973a). Six steps of increasing dissolution of coccoliths are defined and summarized in Table 1.

The five sites can be separated into two groups according to dissolution. Sites 571, 572, and 573 show an alternation of nondissolved and dissolved sections, with the nondissolved greatly predominant. At Sites 574 and 575, dissolution is stronger, and the dissolved sections are predominant. In some cases, dissolution obscures stratigraphy (lower Pleistocene at Site 575); dissolution is always much more severe in the Matuyama than in the Brunhes.

### REWORKING

There is some reworking at all the sites, but it is always more pronounced in the Matuyama than in the Brunhes. From east to west and from south to north, there is a gradation in reworking. It increases from Site 571 to Site 575:

Hole 571: Scarce specimens of the Miocene *Discoaster* spp. in the middle of Core 571-1 (in  $\text{CaCO}_3$  cycles B7 and B6).

Hole 572C: Few *Reticulofenestra* spp. throughout the Brunhes; common specimens of only one species of *Reticulofenestra* in one sample of the Matuyama (572C-3-1, 120 cm).

Hole 573: No reworking in the Brunhes; various *Reticulofenestra* in the Matuyama.

Hole 574: Some *Reticulofenestra* in the Brunhes, which become common in the Matuyama.

Hole 575C: Reworking is especially pronounced in this hole, as indicated by various species from various periods. Medium-sized coccoliths from the Oligocene-Miocene (*Cyclicargolithus abisectus*, *Cyclicargolithus floridanus*, *Coccolithus miopelagicus*) are common in the Brunhes. In the upper part of the Brunhes and mostly in the Matuyama there are some *Reticulofenestra*. *Discoasters* (especially *D. deflandrei*) are present throughout the Quaternary, and they are common in the Matuyama.

### STRATIGRAPHIC METHODS, QUATERNARY OF THE PACIFIC OCEAN

Various stratigraphic methods are used to study the Quaternary in the Pacific Ocean. Paleomagnetic stratigraphy is important in stratigraphic studies; for Leg 85, it is crucial (Weinreich and Theyer, this volume). The isotopic record would also be useful, but for the Quaternary of Leg 85, no oxygen isotope measurements were made.

In the equatorial Pacific, and especially in the high-productivity zone, carbonate stratigraphy is often used. The carbonate content of sediments shows global variations attributed to climate. The interpretation of these fluctuations in the Pacific Ocean was first made by Arrhenius (1952), who correlated  $\text{CaCO}_3$  minima with interglacial periods and maxima with glacial periods. This pioneer was followed by Olausson (1961) and many other researchers; one of the most important papers is by Hays et al. (1969), who studied several Pliocene-Pleistocene cores and gave "names" to some characteristic  $\text{CaCO}_3$  minima related to the magnetostratigraphy: B1 to B17 are the minima in the Brunhes, and M1, M3, M5, M7, M11, and M17 are those in the Matuyama. One of the cores (RC 11-209) studied by Hays et al. (1969) is usually considered a standard Pacific carbonate record. Using this core and Site 503, Gardner (1982) correlated carbonate minima with isotopic stages, although "the carbonate response always lags behind the oxygen isotope response by about 1 to 5 ky." Thus, carbonate cycles can be used for dating.

Short-term variations in carbonate content are "cyclic fluctuations" (Gardner, 1982), with a period of about

Table 1. Nannofossil solution index.

	Dissolution	Abundance of intact coccoliths	Taxonomic diversity	State of solution-resistant structures	State of non-solution-resistant structures
-1	Few coccoliths slightly dissolved	Almost 100%	Normal	Good	Good
-2	Most coccoliths slightly dissolved	About 70%	Normal	Good	Beginning of solution
-3	Most coccoliths moderately dissolved	More than 40%	Few genera and/or species absent	Some central structures missing	Strongly dissolved or missing
-4	Most coccoliths strongly dissolved	About 20%	Weak	Many central structures missing	
-5	Very strong; almost noncalcareous sediment	No intact coccolith	Mono- or bi-specific		
-6	Total dissolution; no calcareous sediment	Barren sediment			

Note: Adapted from Bukry (1973a).

0.5 m.y. They were delineated mostly from late Miocene through early Pliocene. In the Pleistocene, Gardner found shorter periodicities, about 0.095 m.y. for "S-cycles" and 0.041 m.y. for "C-cycles."

The carbonate content was measured in material from three holes (571, 572A, and 573). In the same samples, the nannofossil total abundance was estimated with accuracy. A curve of nannofossil total abundance is a useful stratigraphic tool that reflects climatic changes (in the Atlantic, DSDP Leg 80: Pujos, in press) or varies with bulk CaCO<sub>3</sub> content (in the equatorial Pacific: Labracherie et al., 1981).

Although carbonate dissolution is connected with the CaCO<sub>3</sub> content, in the complex Pacific environment (and especially in this high-productivity area), interpretation of dissolution has to be partly separated from interpretation of carbonate content. Dissolution has its "solution index" (see the previous section on preservation and Table 1), and shows important fluctuations. Fluctuations in dissolution of planktonic foraminifers were interpreted as "Pacific terminations" (Thompson and Saito, 1974). The term "Pacific terminations" is now considered to be isotopic terminology. But (1) no Quaternary isotopic stratigraphy was established on Leg 85, and (2) "terminations" can be used to date and correlate Pleistocene sections in a well-defined area. So I use the term "Pacific terminations" in this study.

In the Quaternary of the Pacific Ocean, siliceous organisms (diatoms and radiolarians) give more detailed stratigraphic data than do carbonate organisms. For nannofossils, very useful zonations were established, subdividing the Quaternary into three or five zones/subzones (Bukry, 1973b; Okada and Bukry, 1980), but nannofossil Quaternary markers are rare: the first appearance of *Emiliania huxleyi* is not easy to use in a light-microscope study; the *Pseudoemiliania lacunosa* last appearance is at 0.475 Ma (Berggren et al., 1980). Leg 85 Quaternary sections are often rich in nannofossils, which show strong variations in quantity and quality. One purpose of this study is to try to find nannofossil species and associations which could be used as stratigraphic

markers of the Quaternary, at least in this part of this ocean.

The appendix provides a complete list of the nannofossil species found in the Leg 85 Quaternary sediments.

#### SITE SUMMARIES

At Sites 571 to 575, the uppermost sediments contain abundant Quaternary coccoliths. Their abundances were estimated with accuracy, and specimens were named, especially various species and variants belonging to the genus *Gephyrocapsa*. Details of the distribution are shown in Figures 2, 3, 5, 6, and 8, and do not require much explanation. The following descriptions of the five sites are restricted to characteristics of the area and a few significant details.

##### Site 571 (03°59.84' N, 114°08.53' W; water depth 3969.5 m)

This very short section (Fig. 2) is restricted to one 7.11-m core representing the uppermost Quaternary. Nannofossils are alternately very abundant and rather scarce, giving a good curve of total abundance. Carbonate minima are evident, from B1 to B11. Dissolution is never important, and "terminations" are not very obvious.

Most of the Quaternary nannofossil species are abundant, chiefly *Emiliania huxleyi* and various *Gephyrocapsa*. *Pseudoemiliania lacunosa* is present in the lowermost part of the section. Some common Quaternary species were not found (*Umbellosphaera irregularis*, *Gephyrocapsa ericsonii*, *Helicopontosphaera neogranulata*). These absences do not seem to be due to dissolution in this section, but perhaps to environmental factors: Site 571 is situated near the northeastern edge of the high-productivity area, in a zone where some upwelling phenomena occur, leading to special environmental features. The presence at the top of the section, of very rare *Coccolithus pelagicus*, unusual in equatorial waters, corroborates this hypothesis.

Sedimentation at Site 571 is continuous between the top (Holocene) and the bottom (which can be dated at about 0.5 Ma). Reworking is very rare and restricted to

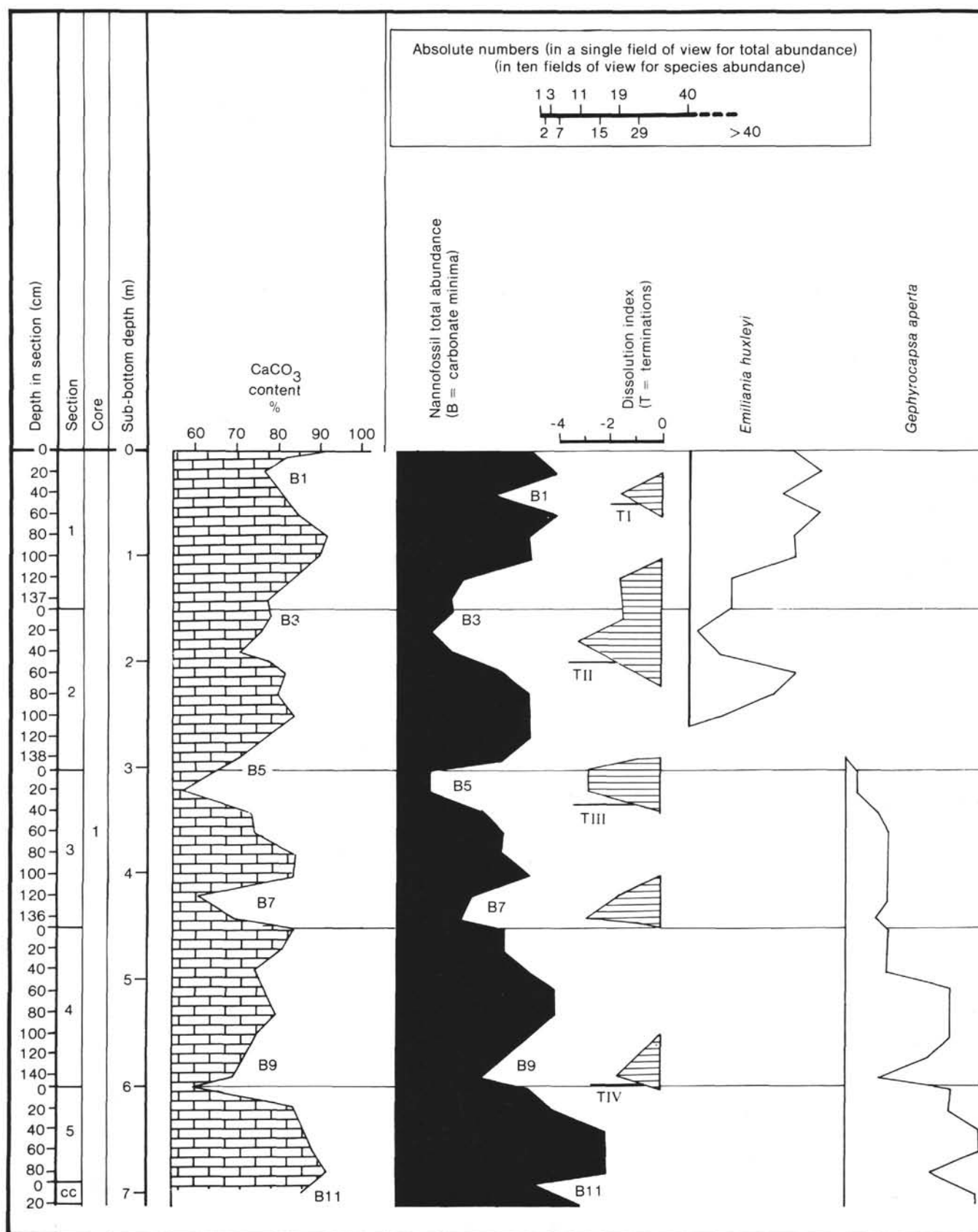


Figure 2. Nannofossils, Hole 571.

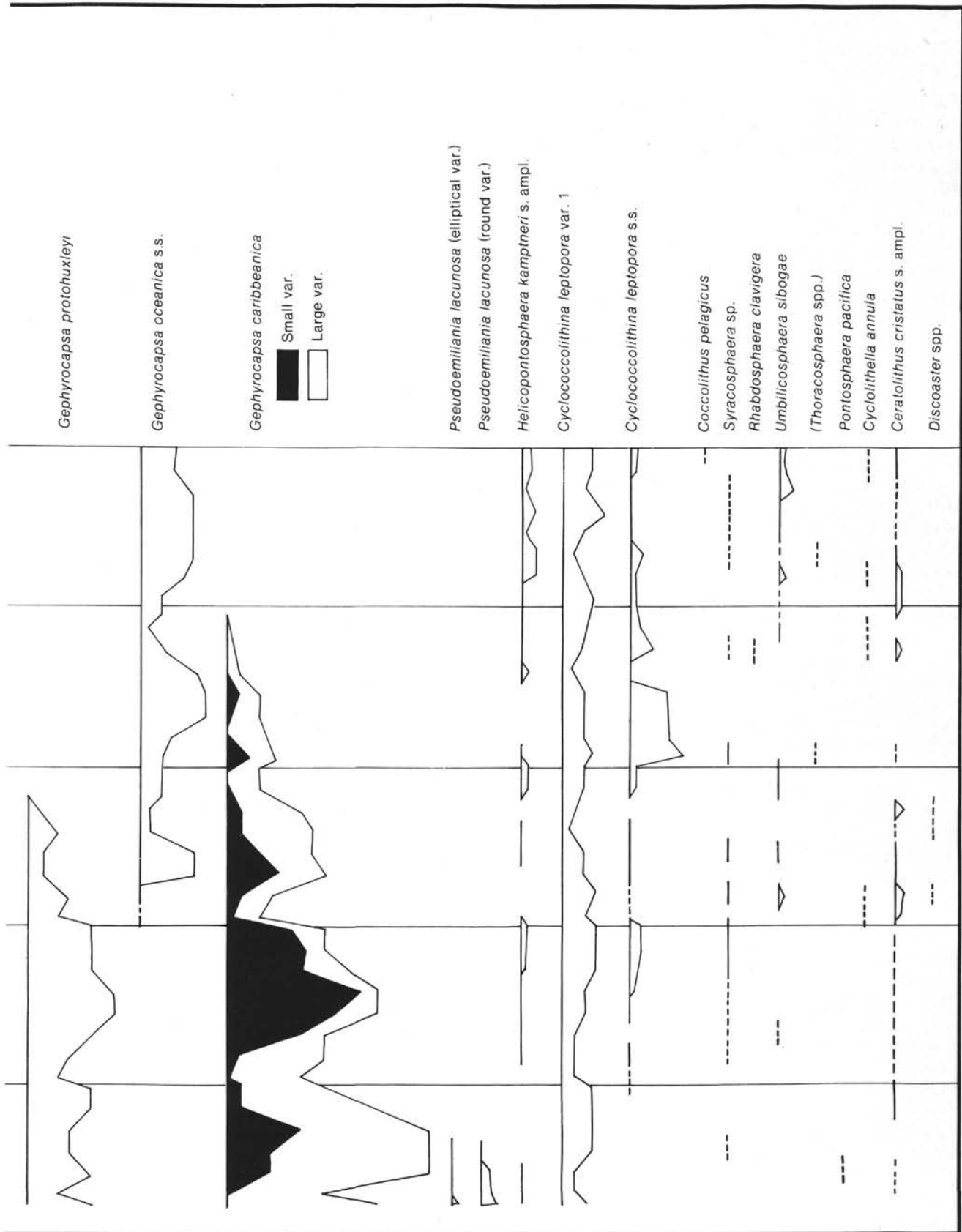


Figure 2. (Continued.)



scarce *Discoaster* spp. in Section 571-1-3 (carbonate cycles B6 to B7).

**Site 572 (01°26.09' N, 113°50.52' W; water depth 3903 m)**

Site 572 (Fig. 3) was cored in the vicinity of Site 81, in the eastern part of the high-productivity area. Five holes were drilled and cored, but only Holes 572, 572A, and 572C yielded Quaternary sediments. Hole 572A was selected for a detailed nannofossil study of the Quaternary, which corresponds to the upper 26 m of the section.

At this site, magnetic intensity is too weak to establish a magnetic stratigraphy; variations of CaCO<sub>3</sub> content give a tentative stratigraphy. The main cycles are easily recognizable on the CaCO<sub>3</sub> curve (Fig. 3) and on the nannofossil total abundance curve. Major cyclic variations (Gardner, 1982) are evident, mostly in the upper part of the section, with a periodicity of about 0.5 m.y. (which would agree with Gardner's long cycles in the Tertiary, but not in the Quaternary).

The results from the two uppermost sections of Core 572A-1 are not very clear, perhaps as a result of slight coring disturbance. The carbonate curve shows strong variations, unlike the comparatively constant nannofossil total abundance. Nevertheless, the nannofossil associations with *Emiliana huxleyi* suggest that the top of Hole 572A is Holocene (CaCO<sub>3</sub> cycle B1).

Nannofossils are almost always abundant, especially between 572A-1-3, 100 cm and 572A-2-4, 80 cm; below, dissolution of coccoliths has much more influence, and the total abundance decreases strongly. This change in the abundance and dissolution occurs between CaCO<sub>3</sub> cycles M2 and M3.

Various species of *Gephyrocapsa* appear and disappear throughout the section, and can be used as stratigraphic markers. *G. doronicoides* and its five variants are very useful (see discussion in subsequent section). "Small *Gephyrocapsa*" (Gartner, 1977) are almost always abundant from 572A-1-2, 60 cm to the Pliocene/Pleistocene boundary; they consist of the species *G. aperta*. I recognized no special "small *Gephyrocapsa*" Zone, which does not seem to be useful in this part of the Pacific.

The Quaternary of Hole 572 can be correlated with that of Hole 572A by means of the nannofossil total abundance, solution index, and some nannofossil markers (Fig. 4). The very top of the section is lacking in Hole 572, where the youngest sediments belong to CaCO<sub>3</sub> cycle B2; the oldest sediments (Section 572-1, CC) are older than cycle M1. The difference in the rate of sediment accumulation is obvious if we compare the two holes: between cycles B2 and M2, there is 12.70 m in Hole 572A and 9.5 m in Hole 572. This difference in thickness is not due to a hiatus in Hole 572, where all the CaCO<sub>3</sub> cycles and the main nannofossil events can be recognized.

**Site 573 (00°29.91' N, 133°18.57' W; water depth 4311.5 m)**

Site 573 (Fig. 5) is the southernmost Leg 85 site, and lies south of the crest of maximum sediment accumula-

tion. It is very close to DSDP Site 77 (Leg 9), which was considered a reference section for the Pacific Neogene (Hays et al., 1972). But at Site 77, Quaternary sediments were not studied in detail. Therefore, special attention was paid to Site 573, which was chosen as the reference section of this study. Three holes were drilled at this site; only Holes 573 and 573B cored Quaternary sediments. Nannofossils of Hole 573 were studied in detail.

A good magnetic stratigraphy (Weinreich and Theyer, this volume) gives the main stratigraphic framework of the Quaternary, and situates the Pliocene/Pleistocene boundary at 573-4-3, 112 cm, at the top of the Olduvai (Berggren et al., 1980).

All CaCO<sub>3</sub> cycles are very clear, but the major cycles (of 0.5 m.y.) are less evident than at Site 572.

The nannofossil total abundance curve shows well-defined maxima compared with the CaCO<sub>3</sub> curve. Nannofossils are almost always abundant, especially between 573-2-1, 120 cm and 573-3-5, 40 cm. Below (between CaCO<sub>3</sub> cycles M4 and M5), dissolution of coccoliths is severe, and strongly reduces the total abundance.

Various species of nannofossils may be used as stratigraphic markers; the succession of species and variants of *Gephyrocapsa* is shown in Fig. 5. Reworking is almost absent, so that Hole 573 provides a good reference section for Quaternary stratigraphy of nannofossils.

**Site 574 (04°12.52' N, 133°19.81' W; water depth 4571 m)**

Site 574 (Fig. 6) is situated north of Site 573 and to the north of the axis of the high-productivity zone. It was cored in the vicinity of DSDP Site 71 (Leg 8). Four holes were drilled at this site, two with Quaternary sediments. Hole 574 was chosen for detailed study of nannofossils.

Quaternary magnetostratigraphy (Weinreich and Theyer, this volume) of Hole 574 shows the Olduvai event clearly, but the Jaramillo is not clearly delimited: there is a normal event between the top of the hole and 574-2-1, 15 cm, above a reversed event which extends down to 574-2-3, 30–55 cm (Weinreich, personal communication, 1983). It is not possible to name the inversion at 574-2-1, 15 cm. The study of nannofossils allows assignment of all of Core 574-1 to the Brunhes. The top of Core 574-2 (between 574-2-1, 0 cm and 574-2-1, 60 cm) seems to be mixed by drilling disturbance, and this agrees with the description of sediments (see site chapter); below 574-2-1, 60 cm, the nannofossil associations indicate an age older than the Jaramillo (mostly because of the first occurrences of *Gephyrocapsa doronicoides* var. 4 and *Gephyrocapsa caribbeanica*).

The CaCO<sub>3</sub> content was not measured at this site. The nannofossil total abundance curve shows strong variations corresponding to CaCO<sub>3</sub> cycles. Thus, it is possible to situate B1 through B14 (B14 seems not to be complete—its lowest part is lacking); below the mixed sediments, M4 to M17 can be located.

These strong fluctuations in nannofossil abundance are the result of dissolution stronger than at Sites 571, 572, and 573, as shown by the solution index curve. Solution is especially strong below the Brunhes: in the mixed part (574-2-1, 0 cm to 574-2-1, 60 cm) and lower, cocco-

liths are reduced in quantity and quality, and difficult to use for precise stratigraphy. In this part of the hole, the smallest species of *Gephyrocapsa* are almost absent, and some *Crenolithus productus* and *G. daronicoides* are present at some levels; solution-resistant *Cyclococcolithina* spp. (Berger, 1973c) are rather abundant.

In general, reworking is unimportant in this hole, but slightly more important in Core 574-2, which contains some small and some big *Reticulofenestra*.

I have tried to correlate the Quaternary of Holes 574 and 574A. Core 1 of Hole 574A has 25 cm of (mixed?) sediment; the upper part of Core 574A-2 is easily correlated with the upper part of Core 2 from Hole 574, using the nannofossil total abundance curve and some nannofossil markers (Fig. 7).

**Site 575 (05°51.00' N, 135°02.16' W, water depth 4550 m)**

Site 575 (Fig. 8) is the northernmost site of Leg 85. It is situated on the northern edge of the high-productivity area, south of the Clipperton Fracture Zone. Three holes were drilled at Site 575. Hole 575C was chosen for the nannofossil study because its two cores seem not to be disturbed.

Magnetic polarity (Weinreich and Theyer, this volume) gives a good stratigraphy of Hole 575C, with the Pliocene/Pleistocene boundary at Sample 575C-1-3, 106–116 cm, the Jaramillo between 575C-1-3, 16–26 cm and 575C-1-3, 6–16 cm, and the Brunhes/Matuyama boundary at 575C-1-2, 106–116 cm.

The CaCO<sub>3</sub> content was not measured in material from Hole 575C. The nannofossil total abundance curve shows clear fluctuations, which can be interpreted as CaCO<sub>3</sub> cycles. The top of the hole is situated in B3; all the Brunhes cycles can be recognized. In the Matuyama, carbonate dissolution is always very strong, so we cannot recognize the M-cycles. Gardner's (1982) major cycles are evident in the upper part of this curve, with a cyclicity of about 0.5 m.y.

At Site 575, nannofossil associations can be used in the Brunhes only, and mostly above B14. Below, and throughout the Matuyama, most of the coccoliths are dissolved, leaving only some solution-resistant species (*Cyclococcolithina* spp. and *Coccolithus pelagicus*).

Reworking is very important at Site 575, with some Oligocene–Miocene species in the Brunhes, several discoasters (mostly *D. deflandrei*) throughout the Quaternary (common in the Matuyama), and various *Reticulofenestra* in the Matuyama.

The Quaternary sections of Holes 575 and 575C can be correlated (Fig. 9). Nannofossil total abundances are very similar; strong dissolution occurs in the lower Brunhes and in the Matuyama in both holes. Nannofossil markers can be used in the Brunhes; in the Matuyama only the solution-resistant species *Cyclococcolithina macintyreii* is usable.

**MORPHOLOGICAL AND STRATIGRAPHIC CHARACTERISTICS OF SOME SELECTED NANNOFOSSILS**

The same taxa are present at almost all the sites. Some of them have already proved useful as stratigraphic mark-

ers, and were correlated with chronostratigraphic scales (Bukry, 1971, 1973a, b; Gartner, 1977; Thierstein et al., 1977; Pujos-Lamy, 1976, 1977; Pujos, in press; Okada and Bukry, 1980; Backman and Shackleton, 1983/1984). Therefore, only certain taxa will be discussed in detail, chosen because they are generally not described precisely, or because new variants must be distinguished to allow a more precise nannofossil stratigraphy, or because they can be regarded as typical of this high productivity zone. Their distribution will be related to the magnetostratigraphy and/or the carbonate stratigraphy.

**The *Gephyrocapsa* Complex**

This group can be subdivided into three major groups (Gartner, 1977), previously described in detail for DSDP Leg 80 (Pujos, in press); only the most important morphological features are mentioned here. The distinction between groups and species is established mostly according to the size of the central area (after Gartner, 1977 and Bukry, 1973a), the dimensions of the outer shield, and/or the aspect of elements. The crossbar is also taken into account (see the variants of *Gephyrocapsa daronicoides*), but not the angle of the bar, because (1) this angle can be measured only when the coccolith lies strictly flat on the slide, which happens very rarely, and (2) it seems to fluctuate greatly within a group or a species. I conclude that the use of bar angles to distinguish species complicates the study of *Gephyrocapsa* and is not really useful in stratigraphy (Pujos, in press).

**The Small *Gephyrocapsa***

Gartner (1977) used this name for a group of very small *Gephyrocapsa* (coccolith length < 2 μm) delimiting a stratigraphic zone between 0.92 and 1.22 Ma (below Jaramillo). A similar acme was not found at the sites of Leg 85.

***Gephyrocapsa aperta* Kamptner.** Two variants were previously described (Pujos-Lamy, 1976), but could not be distinguished at Leg 85 sites, perhaps because of dissolution. This group of *G. aperta* makes up most of the small *Gephyrocapsa* at Leg 85 sites, and is always abundant throughout the Pleistocene, below B3 (Plate 1, Figs. 10–11).

***Gephyrocapsa ericsonii* MacIntyre and Bé.** This is a small species with an elevated bar. It is very rare, but has a very short range (limited to cycle B4), which makes it useful in stratigraphy.

***Gephyrocapsa protohuxleyi* McIntyre.** This species is characterized by the indentations of the outer shield. It was not possible to find—with the SEM—a perfectly characteristic coccolith of the species. Perhaps this aspect of the shield under a light microscope is due to moderate dissolution of another species (possibly *G. caribbeanica*, which has almost the same distribution). Therefore, "*G. protohuxleyi*" is not taken into account in the stratigraphy.

**The Open *Gephyrocapsa***

***Gephyrocapsa oceanica* Kamptner s. s.** (Plate 1, Figs. 1b, 2a, 4a). This medium-sized species (the most important open *Gephyrocapsa*) is moderately abundant in the upper Quaternary; it appears in cycle B10 and is present in sediments up to Recent.

I have described this open *Gephyrocapsa* elsewhere (Pujos, in press).

***Gephyrocapsa oceanica* Kamptner W (warm)** (Plate 1, Figs. 2b, 3). This variant is larger than the species s. s. (greatest length = 2.4 to 3.2 μm for *G. oceanica* s. s. and 4 μm for the warm variant), and it has a larger central opening (opening diameter = 1.2 to 1.8 μm for *G. oceanica* s. s. and about 2.5 μm for the variant). The bar orientation is not taken into account, although it seems to be ecologically significant within this group of open *Gephyrocapsa*. But stratigraphy is the objective of the present paper, and different angles of the crossbar in this species do not seem to be stratigraphically significant (thus *G. omega* Bukry and *G. oceanica* Kamptner var. *californiensis* Kamptner can be considered as ecophenotypic variants of *G. oceanica*).

At Leg 85 sites this large type has a distribution very close to that of *G. oceanica* s. s., but it appears earlier, at about the Brunhes/Matuyama boundary.

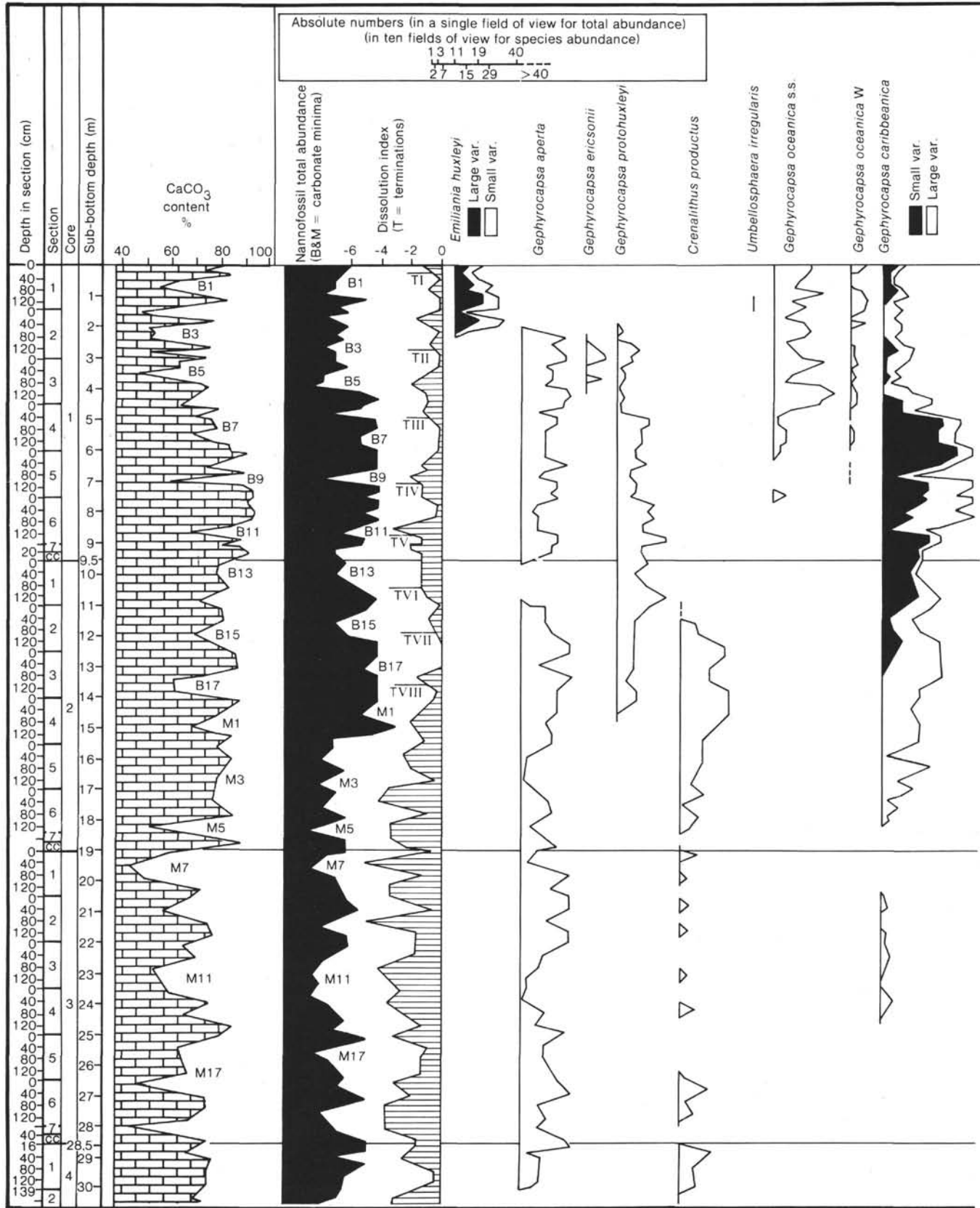


Figure 3. Nannofossils, Hole 572A.



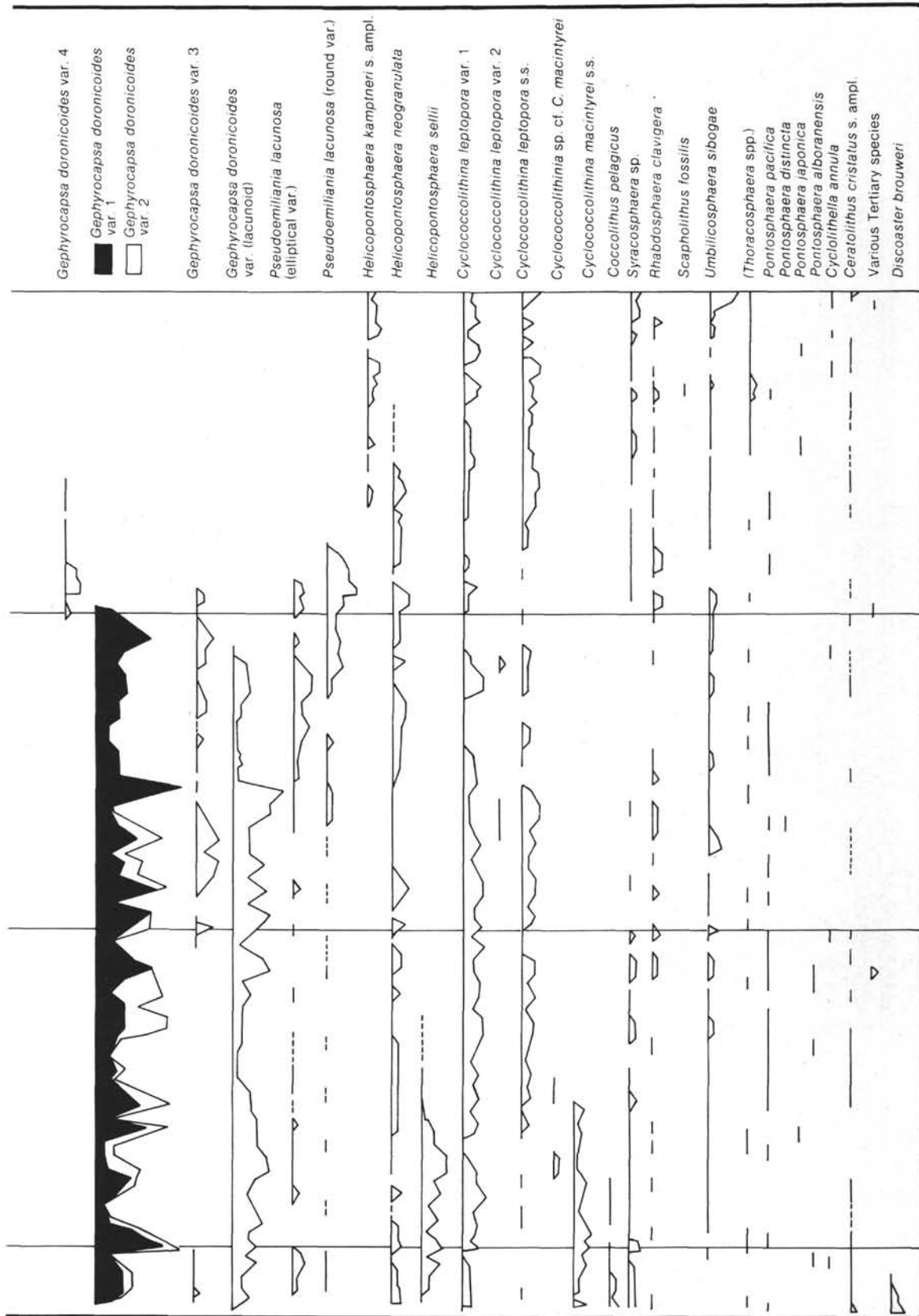


Figure 3. (Continued.)

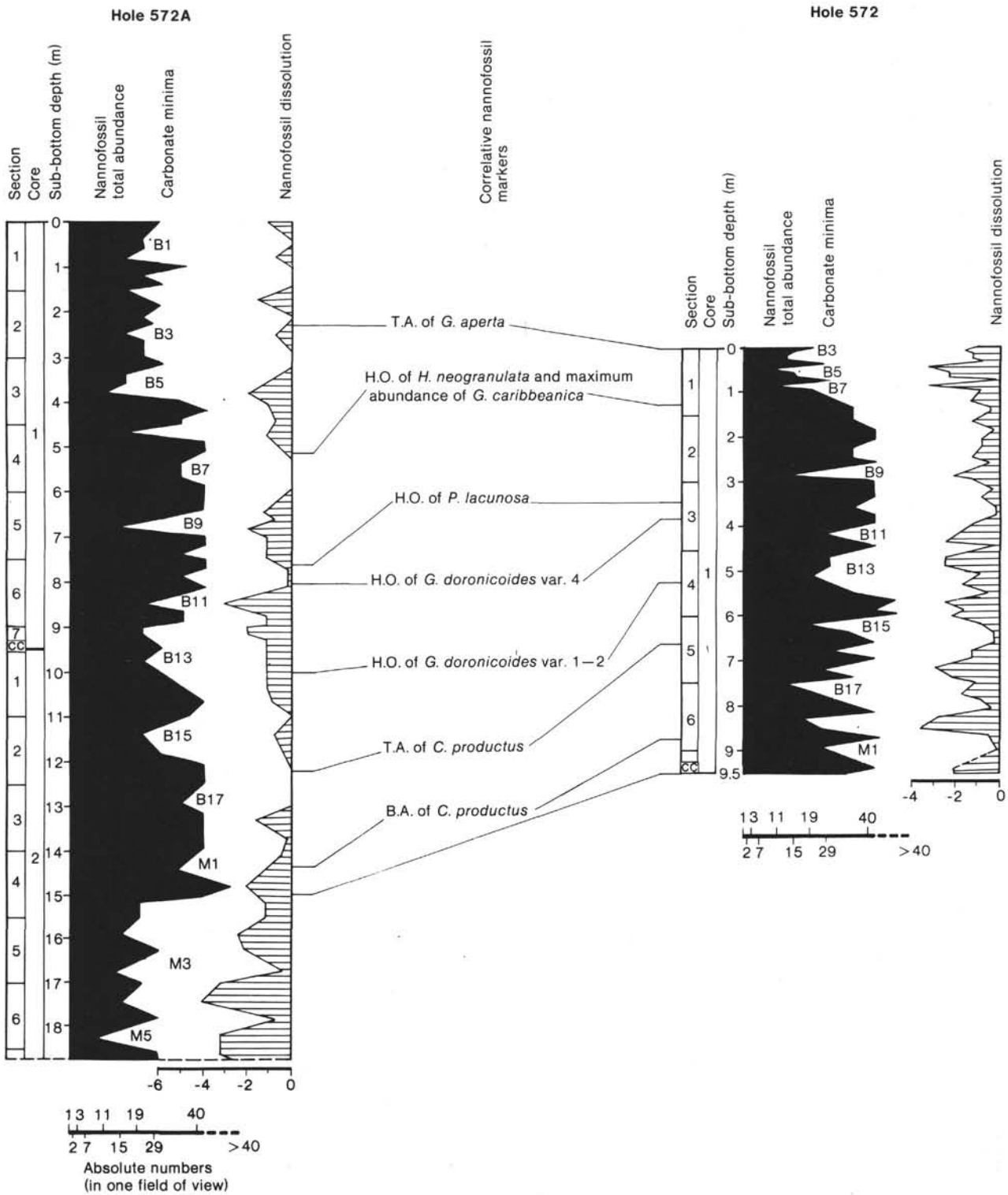


Figure 4. Correlation of Holes 572 and 572A. T.A. = top of acme; H.O. = highest occurrence; B.A. = bottom of acme.

**The Closed *Gephyrocapsa***

This is the most abundant group of Quaternary nannofossils. *Gephyrocapsa caribbeanica* Boudreaux and Hay (Plate 1, Fig. 7). This is a medium-size *Gephyrocapsa* with a crossbar more or less well developed and a slightly open central area. It appears near the boundary between cycles M4 and M5, and it is present till the Holocene. Its acme characterizes the middle part of the Brunhes; the

bottom of the acme is in B15 and its top is in B7 (which agrees with the age of 0.268 Ma given for this event by Thierstein et al., 1977). *Crenalithus productus* (Kamptner) n. comb. (Plate 1, Figs. 4b, 5, 6): *Ellipsoplacolithus productus* Kamptner, 1963, p. 172, pl. 8, figs. 42-44. This *Crenalithus* is placed within the "*Gephyrocapsa* complex" because it resembles *G. caribbeanica*, of which it is probably the ancestor, despite the complete absence of the crossbar. In a previous paper, I therefore named it *Gephyrocapsa producta* (Pujos,

in press), as Bukry did (1973a). It is completely closed, with a slit along the major axis of the coccolith, and is small to medium-sized (greatest length = 3 to 4.5  $\mu\text{m}$ ). Because of this appearance, these specimens might be placed in the species *C. productellus* Bukry (1975). Backman (1980, p. 49) wrote that "the specific epithet *productellus* is a junior synonym of *productus*." So I name this taxon *Crenalithus productus* (Kamptner).

*C. productus* is rare in the Pleistocene; its maximum abundance is between M4 and B15. It disappears in B15. Bukry (1980) situates common specimens of "*Crenalithus productellus*" in his *Crenalithus doronicoides* Zone, which may be equivalent to the period M4 to B15.

***Gephyrocapsa doronicoides* (Black and Barnes).** This is a complex taxon. Its generic attribution is not easy. It was first described as a *Coccolithus*, and this name was used by various authors till 1973, when Roth described a new combination: *Crenalithus doronicoides*. This new name could be all right for various specimens of the species. But as I described in detail (Pujos, in press), some variants have a beginning of a true crossbar (a characteristic of the genus *Gephyrocapsa*); the variants cannot be dissociated from each other but must be placed in the same taxon. The variants have stratigraphic significance.

*G. doronicoides* var. 1 and 2 (Plate 2, Figs. 2-3) are medium-size coccoliths (greatest length = 5 to 6  $\mu\text{m}$ ) with a large (diameter = 2.5  $\mu\text{m}$ , var. 1) or a small (diameter = 1 to 1.5  $\mu\text{m}$ , var. 2) central opening. They usually have a crossbar. They are present in the lowermost Pleistocene and are rather abundant until B12/B13, where they disappear. At Leg 85 sites, it seems that dissolution may have destroyed some parts of the central opening, so that the difference in size of the central opening (which is the distinguishing characteristic) is destroyed. Variants 1 and 2 are therefore not always distinguished from each other in the present study.

*G. doronicoides* var. 3 (Plate 2, Fig. 4) is the giant of the species (greatest length = 8 to 9  $\mu\text{m}$ ), and its size is its characteristic distinction. It is never abundant, but has a useful short range, between M2 and M5.

*G. doronicoides* var. 4 (Plate 2, Fig. 1) is a small coccolith (greatest length = 2.8  $\mu\text{m}$ ) with a small central opening; a crossbar is not always present. The variant may be considered as the end of the lineage. It was found between B8 and B13 (at Sites 571, 572, and 573) and between B9 and B11 (at Sites 574 and 575).

*G. doronicoides* var. (lacunoid) (Plate 2, Figs. 5-6) has a morphology and a size close to that of variant 1 (greatest length = 3.6 to 4  $\mu\text{m}$ ). It can be distinguished by the presence of several slits, giving it the aspect of *Pseudoemiliana lacunosa* when observed with a light microscope; it is present at the bottom of the Pleistocene, and is rare to common till its disappearance at B14/15.

#### ***Pseudoemiliana lacunosa* (Kamptner) (Plate 2, Fig. 7)**

Two types (round and elliptical) are present, and commonly alternate. This species disappears in B10, as was already observed by Hays et al. (1969). The disappearance is dated at 0.474 Ma, worldwide, by Berggren et al. (1980), and can be used for establishing rates of sediment accumulation (discussed in a later section).

#### **The *Helicopontosphaera* Complex (Plate 2, Figs. 8-9)**

I chose this name of *Helicopontosphaera*, following the arguments of Hay (Hay, 1977; Pujos, in press). Three species are present in Leg 85 material:

***Helicopontosphaera neogranulata* Gartner.** This species was tentatively taken as an additional marker at Leg 80 sites (where it disappears at 0.42 Ma); its last appearance occurs at various ages at Leg 85 sites.

***Helicopontosphaera sellii* Bukry and Bramlette.** Considered as an additional marker by Gartner (1977), it disappears in M7, which agrees with the date this author gives for the event (1.22 Ma), but which is later than the date given by Backman and Shackleton (1983/1984) for this event in the equatorial zone (1.37 Ma).

***Helicopontosphaera kamptneri* Hay and Mohler.** The species is taken in its s. ampl., as in Leg 80 material (Pujos, in press). I include in this name some rare specimens of *H. wallichi* (Lohmann), which, according to Haq (1973), is similar in morphology to *H. kamptneri*. *H. kamptneri* s. ampl. occurs sporadically throughout the Quaternary of Leg 85 sites.

#### ***Cyclococcolithina macintyreii* (Bukry and Bramlette) (Plate 3, Fig. 4)**

The two species *leptopora* and *macintyreii* belong to the same genus. This genus cannot be *Calcidiscus* (*Cyclococcolithina* is a "subjective senior synonym because the type species *Calcidiscus quadriforatus* Kamptner is a fragment of *Cyclococcolithina*" [Hay, 1977]) or *Cyclococcolithus* (considered as illegitimate by Loeblich and Tappan, 1970). So the two species (and their variants) are attributed to the genus *Cyclococcolithina*, as established by Wilcoxon (1970), Hay (1977), and Loeblich and Tappan (1971).

Berggren et al. (1980) situate the last appearance of *C. macintyreii* within the Olduvai, Gartner (1977) puts it at 1.51 Ma in the early Pleistocene, and Backman and Shackleton (1983/1984) place it at 1.45 Ma, well after the Olduvai. At Leg 85 sites, this event occurred always after the Olduvai, between M11 and M12, at about 1.50 Ma.

A type of *Cyclococcolithina* is slightly different from the species *macintyreii* s. s.: it is somewhat smaller, with numerous elements and a smaller central opening. I named it *C. sp. cf. C. macintyreii*. It disappeared later than the species s. s., and may be the end of the lineage (Plate 3, Fig. 3).

#### ***Coccolithus pelagicus* (Wallich) (Plate 3, Fig. 5)**

Except for DSDP Site 571, where it is present at the top of the recovered interval, *C. pelagicus* occurs in the Olduvai only, at all sites of Leg 85. It has its last appearance in M17, and does occur in the Pliocene. The distribution of this species was studied in detail by Bukry (1980), who followed its disappearance along a longitudinal transect, in a tropical area situated to the east of the high-productivity zone. The extinction of *C. pelagicus* occurs in the *Emiliana ovata* Subzone (about 0.8 Ma) in the Galapagos area (longitude 86°W); this event has an earlier date to the west, and is situated between the *C. macintyreii* and *Discoaster pentaradiatus* subzones (about 2 Ma) in the Siqueiros area (longitude 106°W). Thus, the last appearance of *C. pelagicus* took place either in the earliest Pleistocene or in the latest Pliocene (see discussion following). At Leg 85 sites, it occurs in the upper part of the Olduvai, which is close to the Pliocene/Pleistocene boundary (about 1.65 Ma).

### **SEDIMENT ACCUMULATION RATES AND NANNOFOSSIL MARKERS**

Sediment accumulation rate curves (Fig. 10) can be drawn using dates of (1) Quaternary magnetic polarity events (Weinreich and Theyer, this volume) for Holes 573, 574, and 575C, (2) extinction of *Pseudoemiliana lacunosa* at 0.474 Ma (Berggren et al., 1980) at the five sites, and (3) some  $\text{CaCO}_3$  minima: carbonate minima are used for Hole 572A, where magnetostratigraphy could not be established. Precise dates are not given for carbonate events, but only their positions close to some polarity event: cycle B17 occurs just above the Brunhes/Matuyama boundary, M3 above the top of Jaramillo, and M17 in the upper Olduvai.

Holes 571, 572A, and 573 have very similar curves, with rates of sediment accumulation between 10 and 25 m/m.y. Hole 574 has a rate between about 4.5 and 16 m/m.y. and the rate for Hole 575C is between 1 and 4 m/m.y. In each case the lowest rate is in the Matuyama and the highest one is between the extinction of *P. lacunosa* and the Brunhes/Matuyama boundary.

By using sediment accumulation rate curves, it is possible to plot a chronological scale for each Quaternary site (Fig. 11 and Table 2) and to date nannofossil markers.

The succession of nannofossil events is shown in Figure 11. The events consist of highest and lowest occurrences, of tops and bottoms of acmes, and a change in dominance of two species. Some of these markers are usually taken as datums in the literature: highest occurrences of *Pseudoemiliana lacunosa*, *Cyclococcolithina*

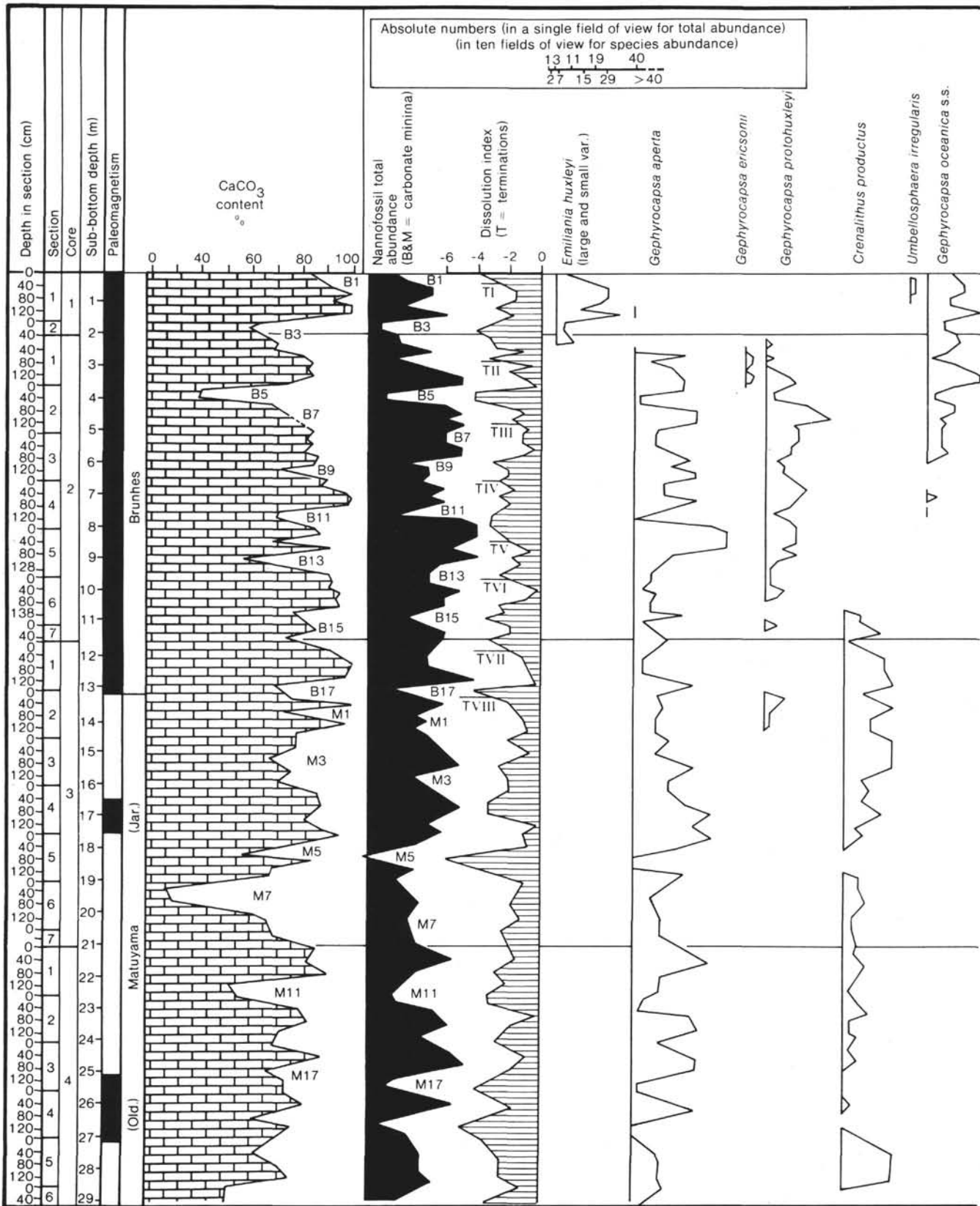


Figure 5. Nannofossils, Hole 573.



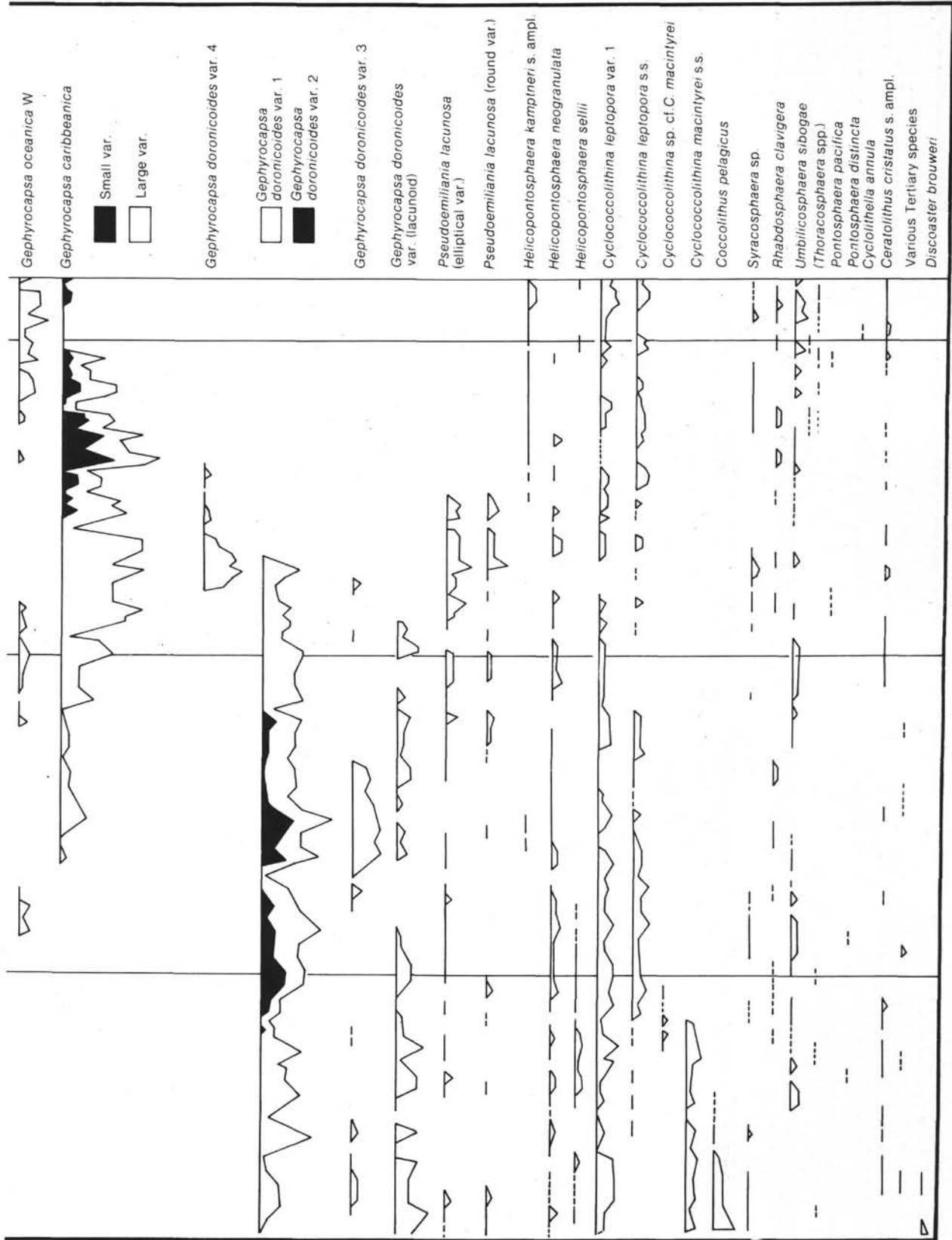


Figure 5. (Continued.)

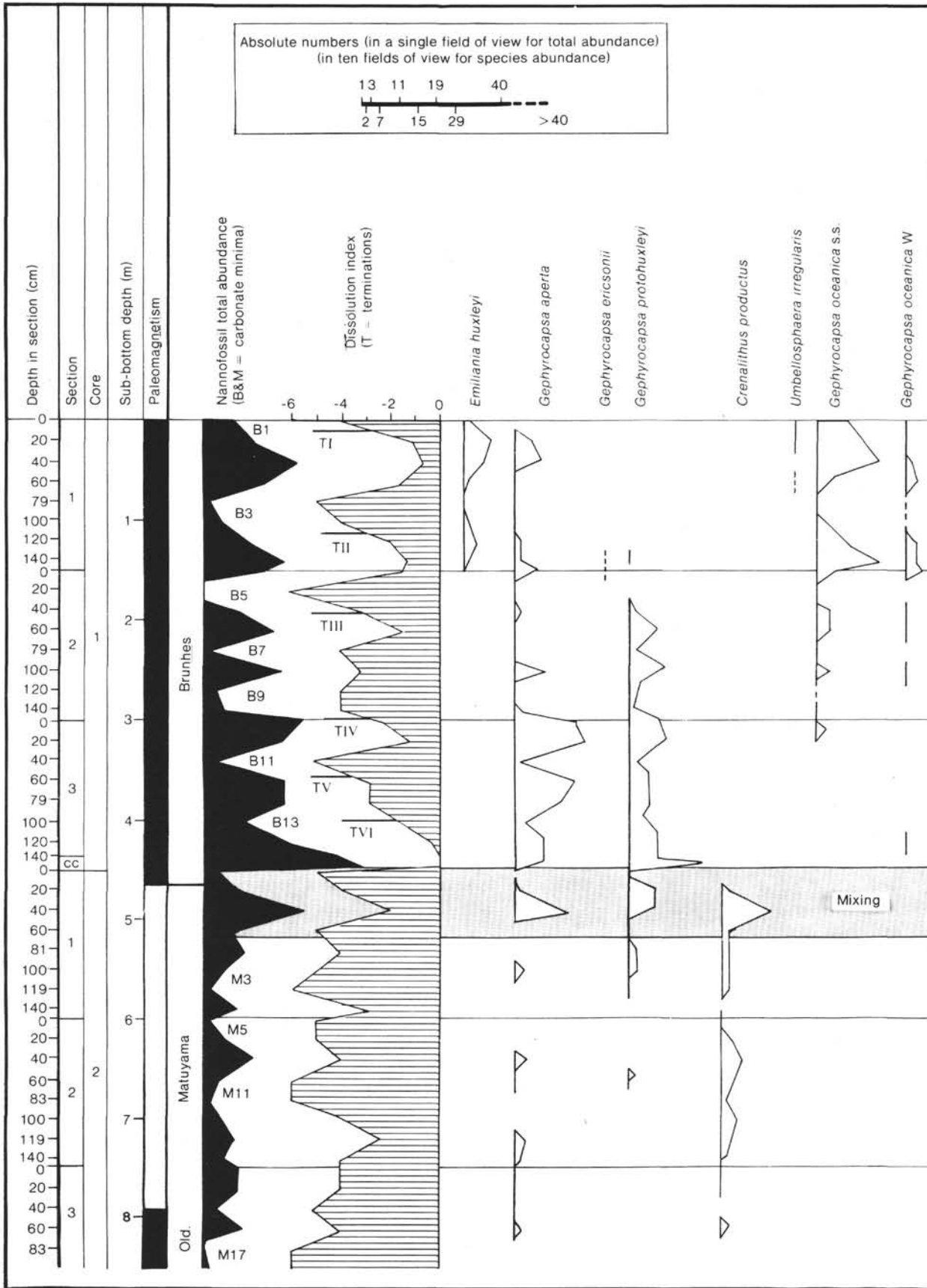


Figure 6. Nannofossils, Hole 574.

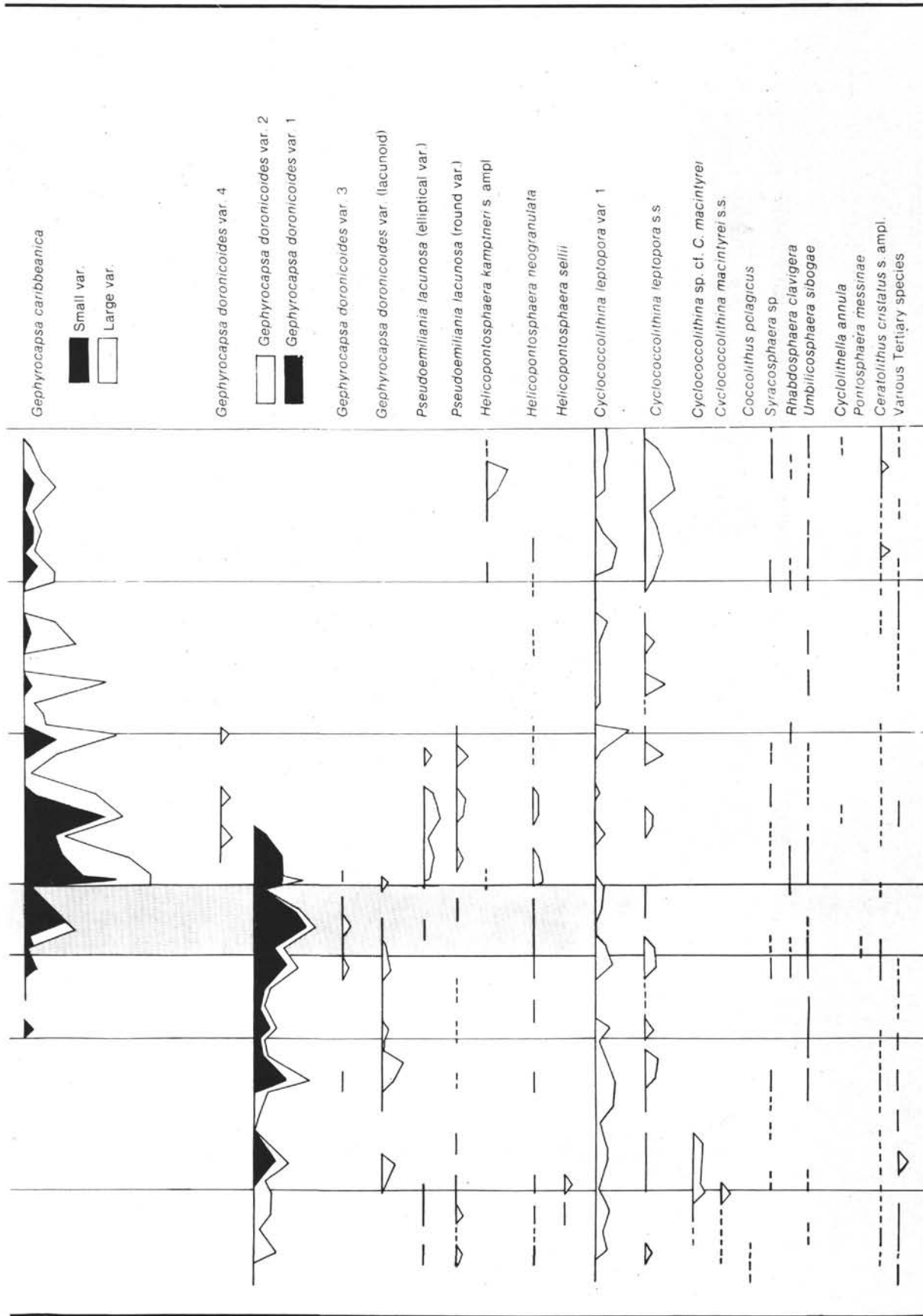


Figure 6. (Continued.)

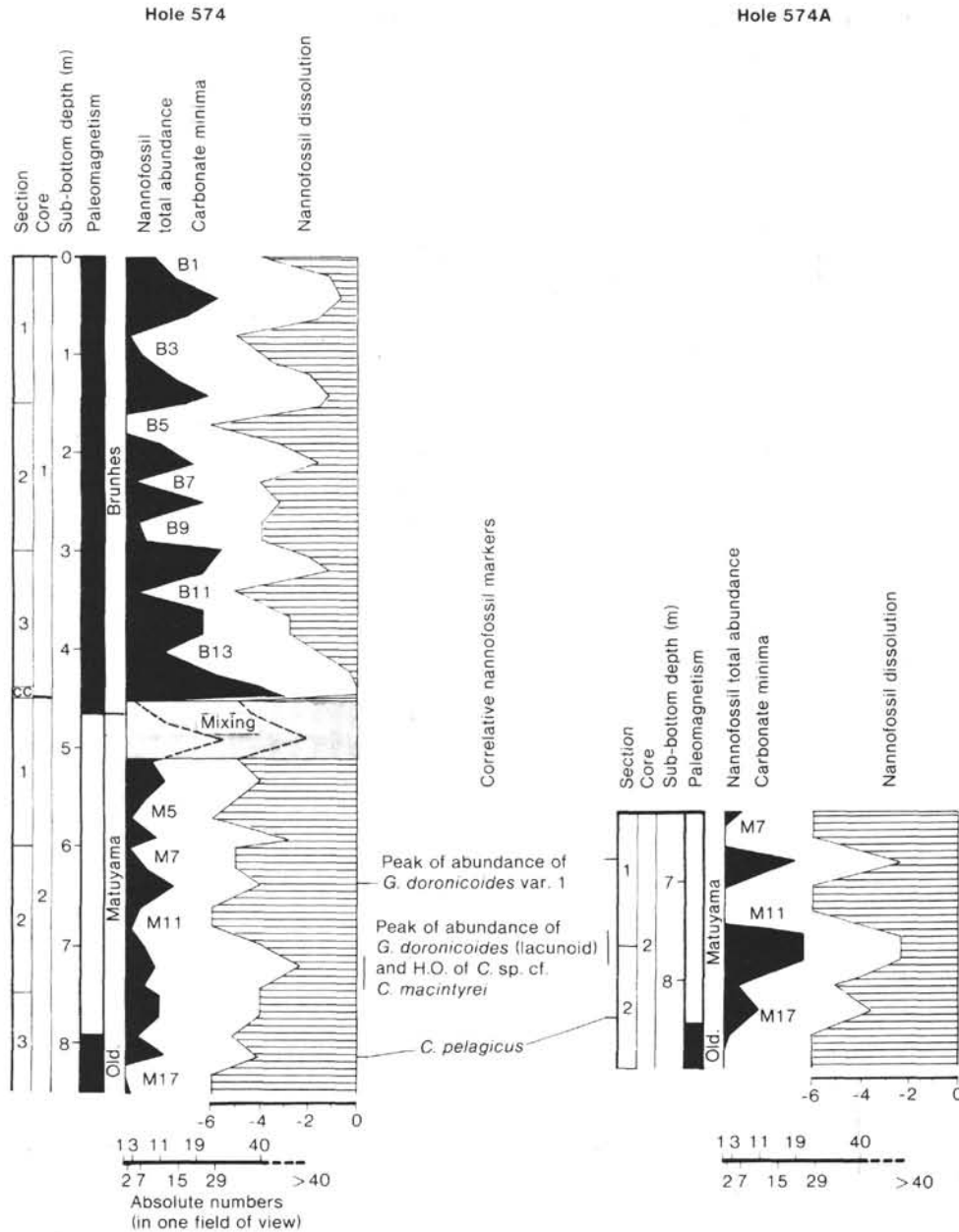


Figure 7. Correlation of Holes 574 and 574A. H.O. = highest occurrence.

*macintyreii*, and *Discoaster brouweri*. For the two latter taxa, see the section on the Pliocene/Pleistocene boundary.

Some conventional markers were found: the change in dominance of *Emiliania huxleyi* and *Gephyrocapsa caribbeanica* (about 0.11 Ma, Thierstein et al., 1977), and the extinction of *Helicopontosphaera sellii* (about 1.22 Ma, Gartner, 1977). Some of these markers can be used only at Sites 571, 572, and 573; they are absent at Sites 574 and 575, because of stronger dissolution.

Some additional markers, previously described using material recovered in the northeastern Atlantic Ocean (Pujos, in press: DSDP Leg 80), are found also at Leg 85 sites, at about the same chronostratigraphic levels as at Leg 80 sites (Table 2). These are *Gephyrocapsa oceanica* s. s., *Gephyrocapsa doronicoides* s. ampl., *Crena-*

*lithus productus*, *Cyclococcolithina* sp. cf. *C. macintyreii*, and *Coccolithus pelagicus*. They may be considered as cosmopolitan markers. Some other markers—mostly the “small *Gephyrocapsa*” of Gartner’s zonation (1977)—were not recognized in the present study; this may be due to the environmental conditions in the equatorial Pacific, which may make these markers less reliable.

### THE PROBLEM OF THE PLIOCENE/PLEISTOCENE BOUNDARY

Nannofossil characteristics of the Pliocene/Pleistocene boundary have been often discussed. Usually the extinction of *Discoaster brouweri* is assumed to be synchronous with this boundary; this disappearance occurs often at the top of the Olduvai or within it (Berggren et al., 1980). In the equatorial Pacific, Hays et al. (1969)



observed "a sharp reduction in number [of *D. brouweri*] just above the base of the Olduvai event, or [it] disappears well below the Olduvai, probably because of solution." At Leg 85 sites, *D. brouweri* disappears distinctly below the Olduvai, even when dissolution is weak (Holes 572A and 573). According to Backman and Shackleton (1983), "*D. brouweri* shows a consistent extinction datum immediately below the base of the Olduvai subchron," at 1.88 Ma.

Bizon and Müller (1978) proposed *Cyclcoccolithina macintyreii* as the marker species for the boundary in the Mediterranean, the extinction of this taxon being dated at 1.51 Ma by Gartner (1977) and at 1.45 Ma by Backman and Shackleton (1983). Bukry (1980) reviewed various papers on this disappearance, which may occur from the middle of the Olduvai to far above this event. At the Leg 85 sites, *C. macintyreii* disappears well above the Olduvai, at about the extinction date given by Gartner.

Thus, the Pliocene/Pleistocene boundary at the Leg 85 sites must be situated between these two nannofossil markers: the disappearance of *D. brouweri* well below the Olduvai and the disappearance of *C. macintyreii* well above the Olduvai. There is about 0.5 m.y. between them. So the position of Berggren et al. (1980) seems to be the wiser one; they place the Pliocene/Pleistocene boundary at the extreme top of the Olduvai.

#### CORRELATION OF THE FIVE LEG 85 SITES

The detailed study of nannofossils provides various stratigraphic criteria. Site 571 is different from the four others because only the uppermost Quaternary was cored, and also because its location, on the edge of the high-productivity area, induces different environmental conditions. Therefore, some nannofossil events were not observed at this site. At the four other sites, correlation is easy, using nannofossil markers and nannofossil total abundance only. The discussion below starts with Site 573, which has the most complete succession of events. It is possible to distinguish two groups of sites.

#### Sites 573 and 572 (and 571)

In the section on rates of sediment accumulation, these three sites were grouped together. Holes 572A and 573 have almost the same thickness of Quaternary sediments, but some differences are evident, mostly in the Matuyama. Some events are distinct at Hole 573, and were not found at separate levels in Hole 572A: bottom of the acme of *Crenalithus productus*, lowest occurrence of *Gephyrocapsa caribbeanica*, and bottom of the acme of *Gephyrocapsa doronicoides*. This may be attributable to a hiatus of about 0.12 m.y. in Hole 572A, or to special environmental conditions.

Sites 572 and 573 are similar in nannofossil total abundance. They show a high-frequency alternation of minima and maxima, with a relatively low amplitude.

#### Sites 574 and 575

Quaternary sediments are reduced in thickness at Sites 574 and 575. This leads to the apparent superposition of

some nannofossil events in the same sample. But the general succession of events is the same as at the other Leg 85 sites, and can be used in the same way.

The nannofossil total abundance fluctuates strongly; especially at the CaCO<sub>3</sub> minima, the abundance is very low, and sometimes completely nil. In such samples the only nannofossils present are usually reworked Tertiary. These two coincident features (near absence of Quaternary plankton and presence of reworked specimens) are probably caused by the same phenomenon. Only a deep current (AABW) could explain the nannofossil composition in the CaCO<sub>3</sub> minima of the cycles; it has dissolved the *in situ* flora and brought in Tertiary coccoliths and discoasters.

Major carbonate cycles can be observed easily in the sections from Holes 574 and 575C, with the most important maximum in cycle B14 and the less important maximum in B5. In these two holes, dissolution is dominant below B14, even in maxima cycles; this interval corresponds to a thin section of sediments in the Matuyama, and carbonate cycles are very difficult to determine.

#### CONCLUSION

The use of nannofossils in correlating Quaternary sections gives detailed and precise results. Besides conventional datums, various additional markers proved useful for regional stratigraphy. A synthesis of the most important stratigraphic results is given in Table 2, where these results are also related to Okada and Bukry's (1980) nannofossil zonation. Supplementary markers were previously used in the northeastern Atlantic Ocean (DSDP Leg 80: Pujos, in press), where they were found in the same succession but sometimes at different age levels. This problem of correlating events of different ages according to location is inherent in Quaternary nannofossils. The solution of this problem will necessitate the study of many Quaternary sections at various latitudes; we can test whether the supplementary nannofossil events can be used worldwide.

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#### APPENDIX

##### List of Quaternary and Tertiary Nannofossils Found in Quaternary Sediments of DSDP Leg 85 (in alphabetic order of species names)

###### Quaternary Species

- Pontosphaera alboranensis* Bartolini, 1970  
*Cyclolithella annula* (Cohen) Cohen and Reinhardt, 1968  
*Gephyrocapsa aperta* Kamptner, 1963  
*Gephyrocapsa caribbeanica* Boudreaux and Hay, 1967  
*Rhabdosphaera clavigera* Murray and Blackman, 1898  
*Ceratolithus cristatus* Kamptner, 1950  
*Gephyrocapsa doronicoides* (Black and Barnes) Pujos, in press  
*Gephyrocapsa ericsonii* McIntyre and Bé, 1967  
*Scapholithus fossilis* Deflandre, 1954  
*Emiliania huxleyi* (Lohmann) Hay and Mohler, 1967  
*Umbellosphaera irregularis* Paasche, 1955  
*Pontosphaera japonica* (Takayama) Burns, 1973  
*Helicopontosphaera kamptneri* Hay and Mohler, 1867  
*Pseudoemiliania lacunosa* (Kamptner) Gartner, 1969  
*Cyclococcolithina leptopora* (Murray and Blackman) Wilcoxon, 1970  
*Pontosphaera messinae* Bartolini, 1970  
*Cyclococcolithina macintyreii* (Bukry and Bramlette) Hay, 1977  
*Helicopontosphaera neogranulata* Gartner, 1977  
*Gephyrocapsa oceanica* Kamptner, 1943  
*Pontosphaera pacifica* Burns, 1973  
*Coccolithus pelagicus* (Wallich) Schiller, 1930  
*Crenolithus productus* (Kamptner) n. comb.  
*Gephyrocapsa protohuxleyi* McIntyre, 1970  
*Helicopontosphaera sellii* Bukry and Bramlette, 1969  
*Umbilicosphaera sibogae* (Weber and van Bosse) Gaarder, 1970  
*Helicopontosphaera wallichi* (Lohmann) Boudreaux and Hay, 1969

###### Tertiary Species

- Cyclicargolithus abisectus* (Müller) Wise, 1973  
*Discoaster brouweri* Tan Sin Hok, 1927  
*Discoaster deflandrei* Bramlette and Riedel, 1954  
*Amaurolithus delicatus* Gartner and Bukry, 1975  
*Cyclicargolithus floridanus* (Roth and Hay) Bukry, 1971  
*Coccolithus miopelagicus* Bukry, 1971  
*Reticulofenestra pseudoumbilica* (Gartner) Gartner, 1969

Table 2. Correlation between nannofossil zonation of Okada and Bukry (1980), nannofossil events, chronologic scale, carbonate cycles, and some isotopic stages in the Pacific (Leg 85) and in the Atlantic (Leg 80).

Okada and Bukry (1980) low-latitude zonation		Nannofossil conventional (marked [conv.]) and additional markers				
Zones	Subzones	Leg 85		Nannofossil events	Leg 80	
		Estimated ages (Ma)	Carbonate cycles		Climatic (= isotopic) cycles	Estimated ages (Ma)
CN15 <i>E. huxleyi</i>	CN14b <i>Ceratolithus cristatus</i>	0.13-0.17	B3/B4	Change of dominance between <i>E. huxleyi</i> and <i>G. caribbeanica</i> [conv.]	5	0.11
		0.15	Top B4	HO of <i>G. ericsonii</i>		
		0.23	Bottom B4	LO of <i>G. ericsonii</i>		
		0.3-0.4	B7/B8	Acme top of <i>G. caribbeanica</i>	7/8	0.25
		0.32	Top B7	HO of <i>H. neogranulata</i>	12	0.42
		0.38-0.45	B8 to B10	HO of <i>G. doronicoides</i> var. 4	12/13	0.32
		0.475	B10	HO of <i>P. lacunosa</i> [conv.]		0.475
		0.4-0.5	B10/B11	LO of <i>G. oceanica</i> [conv.]	12	0.63
		0.55	B12	HO of <i>G. doronicoides</i> var. 1-2		0.45
		0.58	B12/B13	LO of <i>G. doronicoides</i> var. 4	12	0.45
		0.62	B14/B15	HO of <i>G. doronicoides</i> (lacunoid)	0.58 <sup>a</sup>	0.55
		0.63	B14/B15	HO of <i>C. productus</i>		0.63
		0.65	B15	Acme bottom of <i>G. caribbeanica</i>	1.22 <sup>a</sup>	0.63
		0.8	M2/M3	Acme top of <i>G. doronicoides</i> var. 3		1.22 <sup>a</sup>
		0.96	M4/M5	Acme bottom of <i>C. productus</i>	1.22	1.22
0.98	M4/M5	LO of <i>G. caribbeanica</i>	1.22			
1.050	M5	Acme bottom of <i>G. doronicoides</i> var. 3	1.22	1.22		
1.230	M7	HO of <i>H. sellii</i> [conv.]		1.22		
1.350-1.450	M10/M11	HO of <i>C. sp. cf. C. macintyreii</i> [conv.]	1.51	1.51		
1.500	M11/M12	HO of <i>C. macintyreii</i>		1.65		
1.650	M16/M17	HO of <i>C. pelagicus</i>	1.63	1.63		
1.750	M17/M18	Acme bottom of <i>G. doronicoides</i> var. 1-2		1.63		
1.8 Ma	CN12d <i>C. macintyreii</i>	>2.0		HO of <i>D. brouweri</i>		

Note: HO = highest occurrence; LO = lowest occurrence.

<sup>a</sup> On Leg 80, a distinction was established between *C. productus* s. s. and *G. sinuosa* (which may be a variant of *C. productus*).

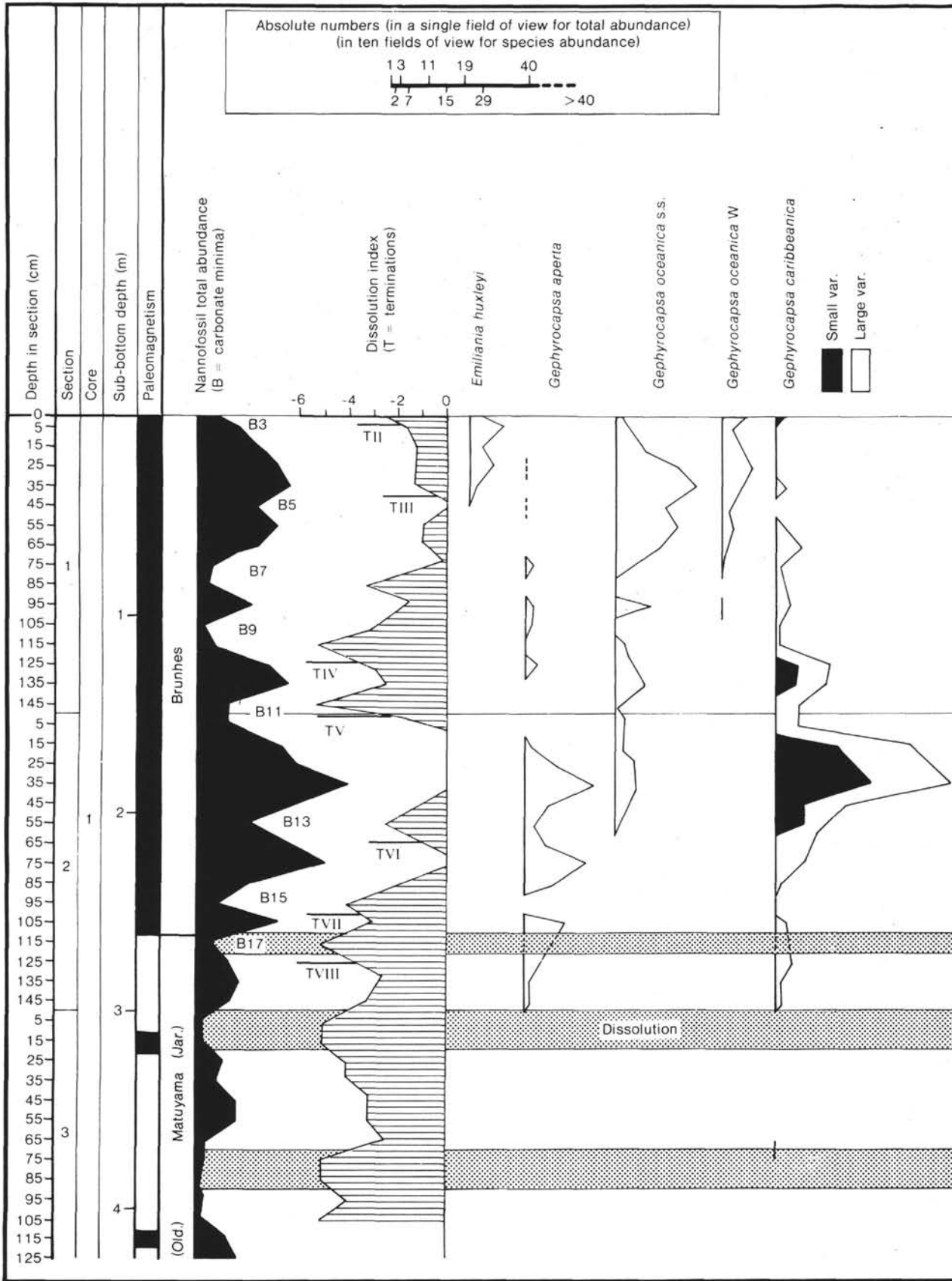


Figure 8. Nannofossils, Hole 575C.



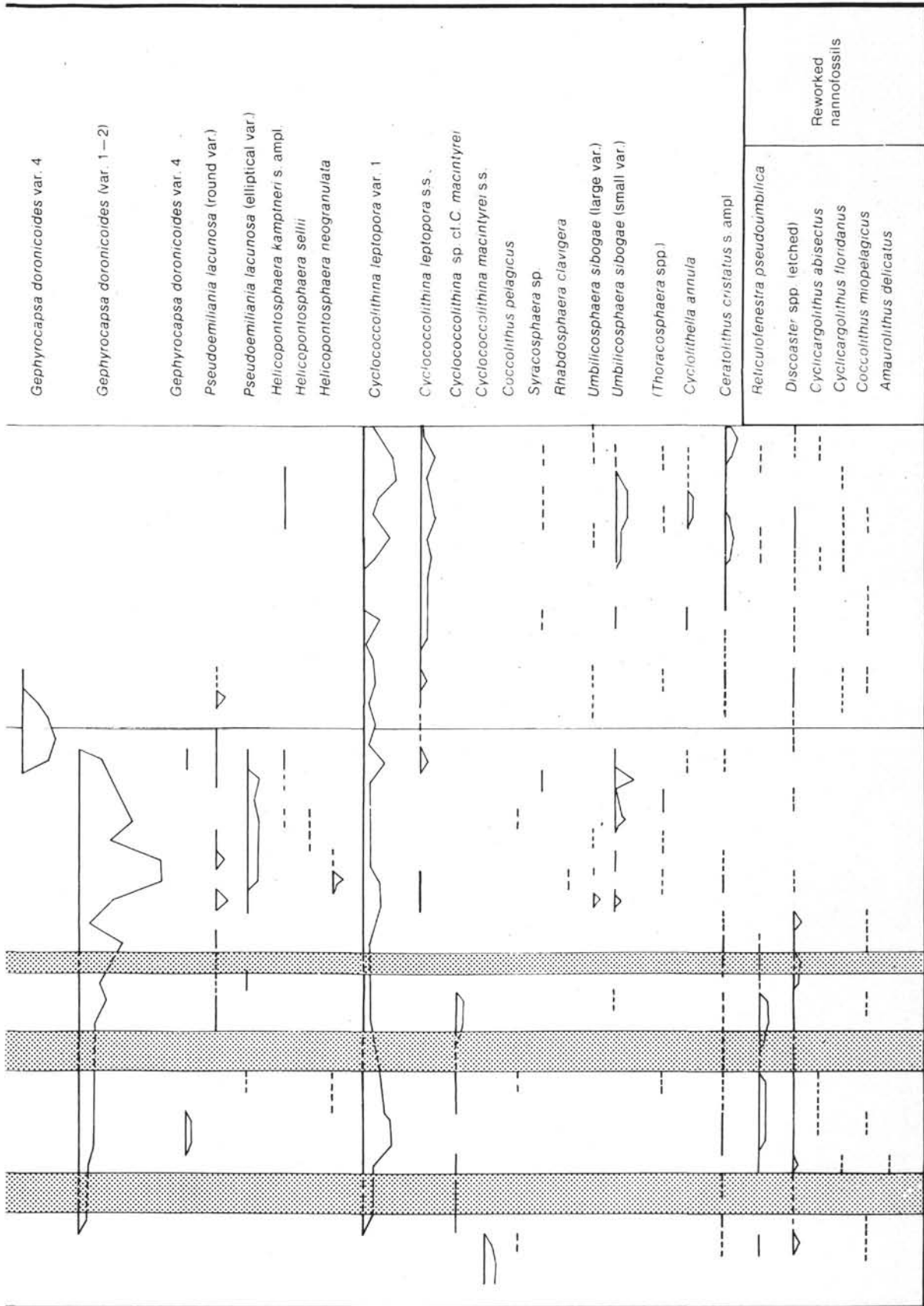


Figure 8. (Continued.)

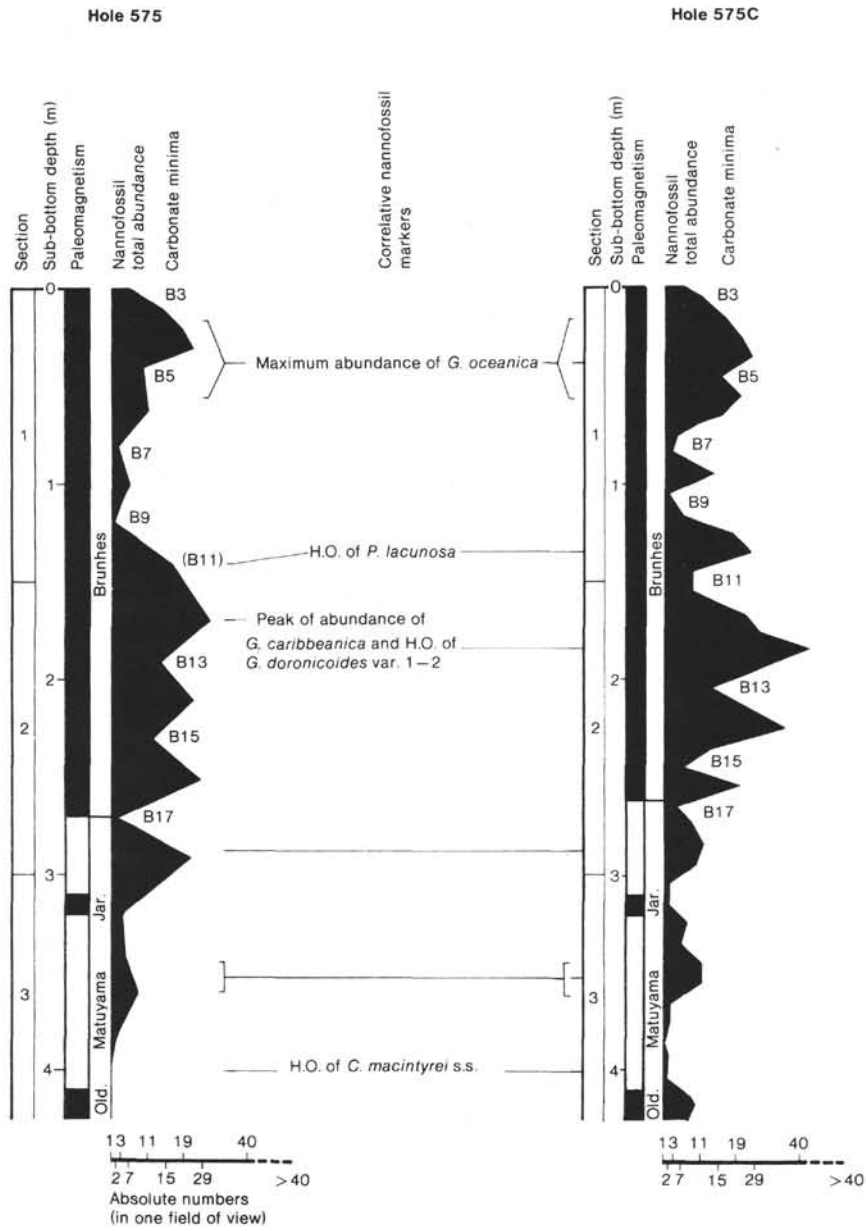


Figure 9. Correlation of Holes 575 (Core 1) and 575C (Core 1). H.O. = highest occurrence.

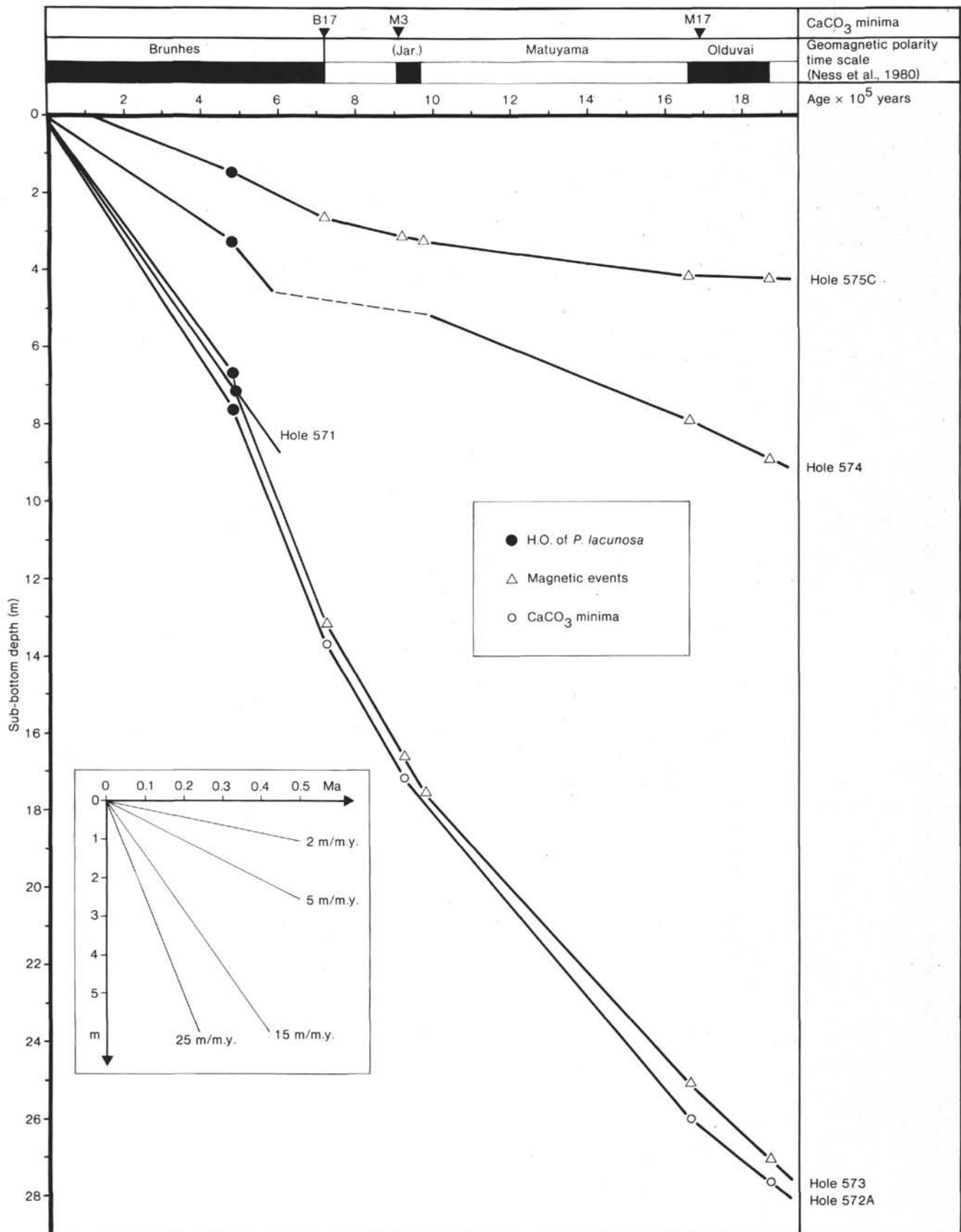


Figure 10. Sediment accumulation rates. H.O. = highest occurrence.

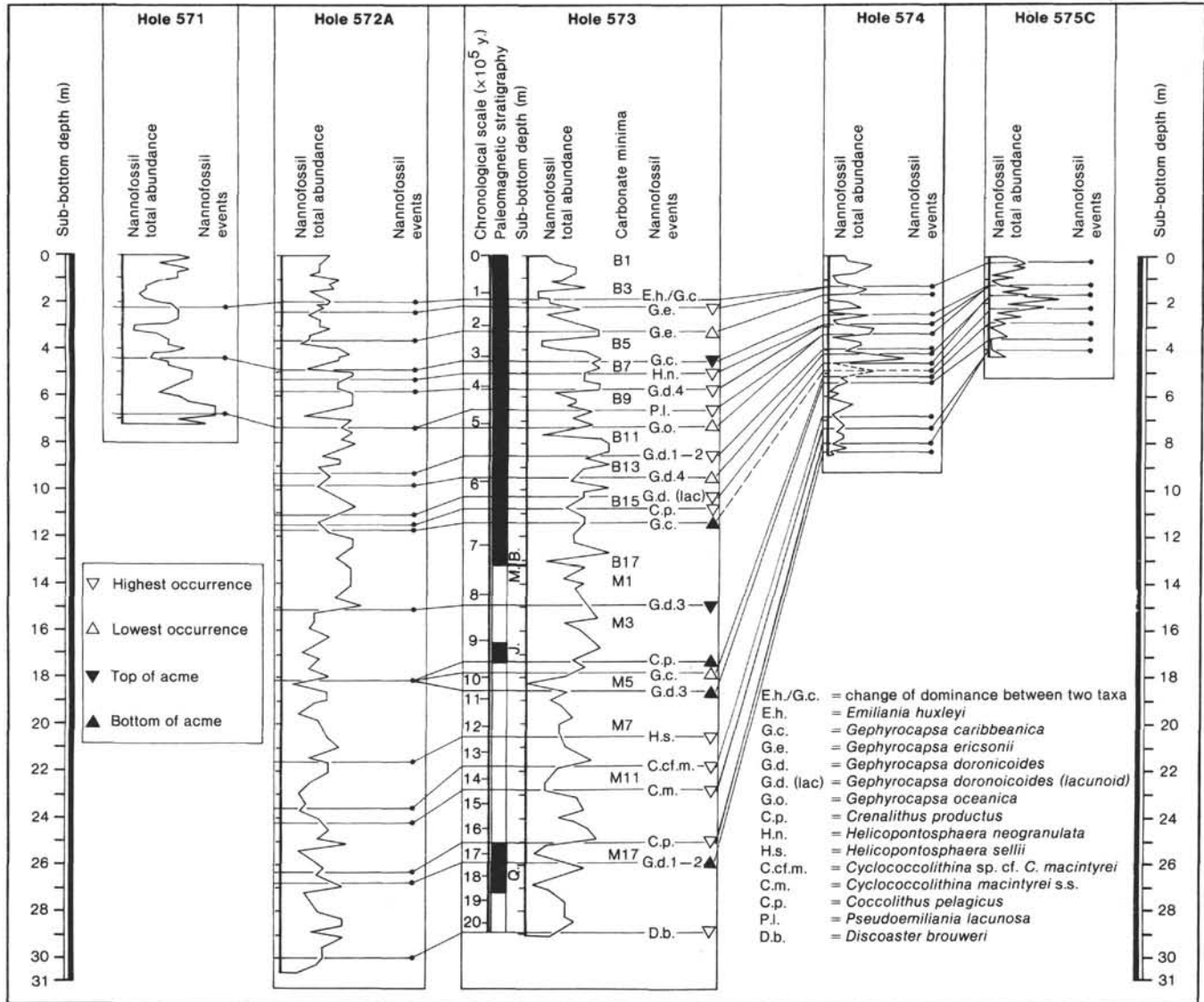


Figure 11. Correlation of Holes 571, 572A, 573, 574, and 575C, using nannofossil total abundance and nannofossil markers.



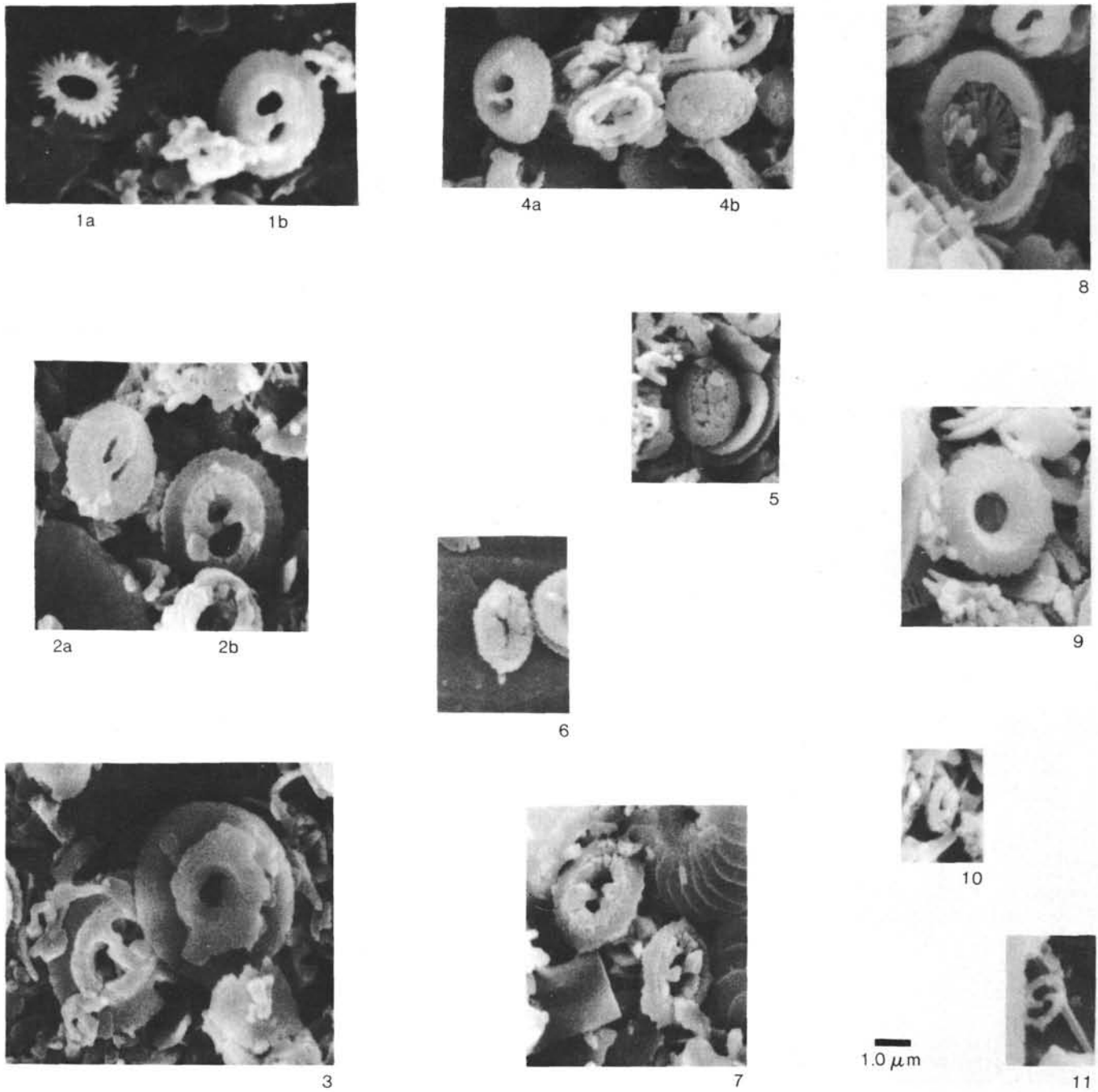


Plate 1. Quaternary nannofossils from Leg 85 sites. (SEM; magnification  $\times 6000$ .) **1a.** *Emiliana huxleyi*, 573-1-1, 40 cm. **1b, 2a, 4a.** *Gephyrocapsa oceanica* s. s., (1b) 573-1-1, 40 cm, (2a) 573-2-6, 40 cm, (4a) 573-2-6, 138 cm. **2b, 3.** *Gephyrocapsa oceanica* W, 573-2-6, 40 cm, (3) includes a *Cyclococcolithina leptopora* var. 1. **4b, 5-6.** *Crenalithus productus*, (4b) 573-2-6, 138 cm, (5) 573-3-1, 120 cm, (6) 573-3-3, 40 cm. **7.** *Gephyrocapsa caribbeanica*, slightly dissolved specimens, 573-2-5, 40 cm. **8.** *Syracosphaera* sp., 573-2-5, 40 cm. **9.** *Umbilicosphaera sibogae*, 573-3-3, 40 cm. **10-11.** *Gephyrocapsa aperta*, (10) 573-3-3, 40 cm, (11) 573-2-2, 100 cm.

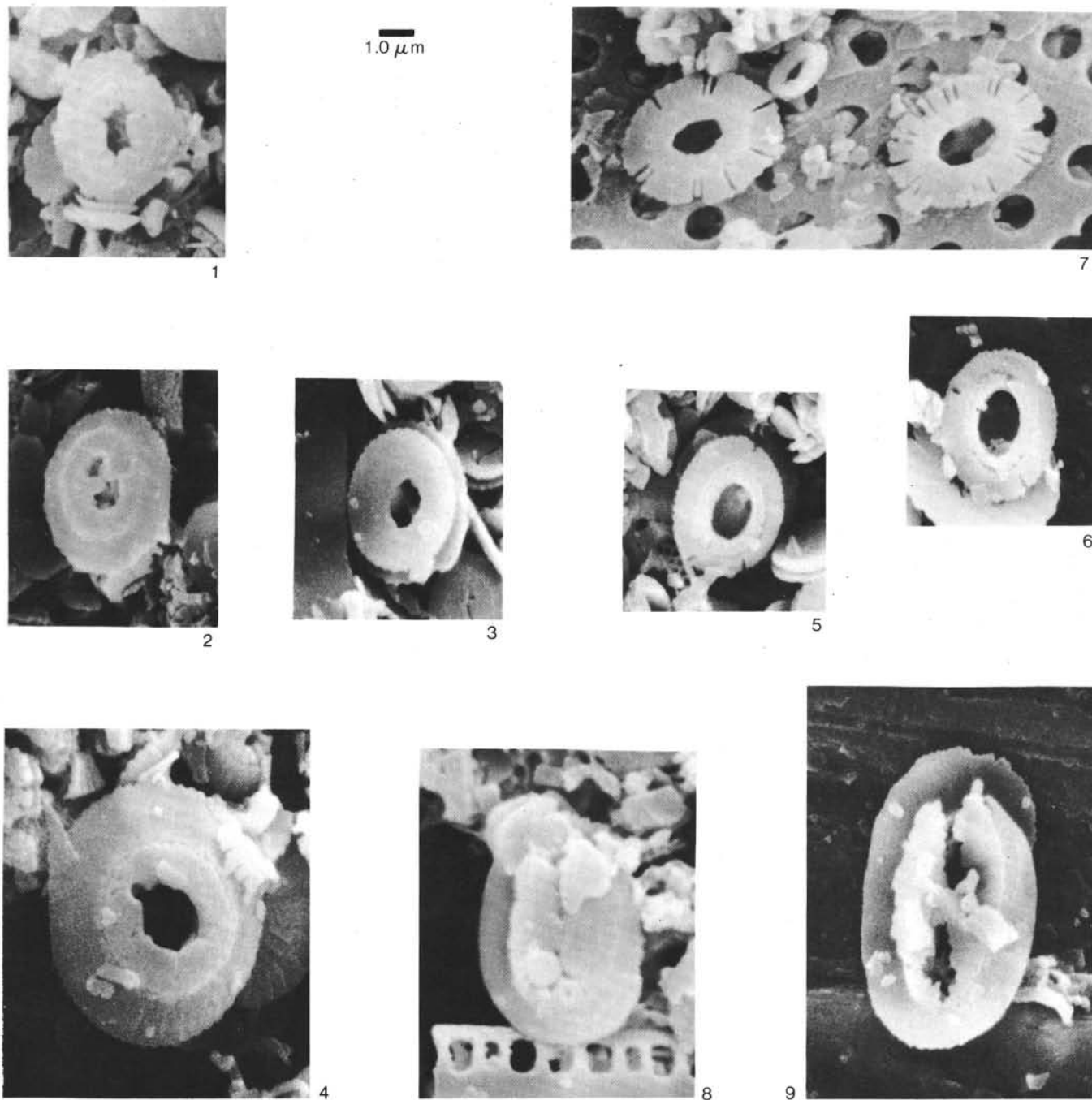
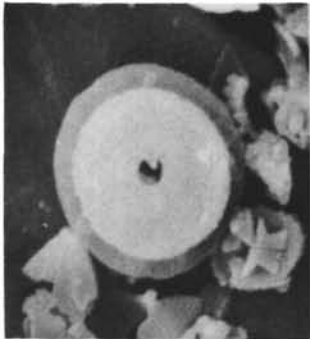
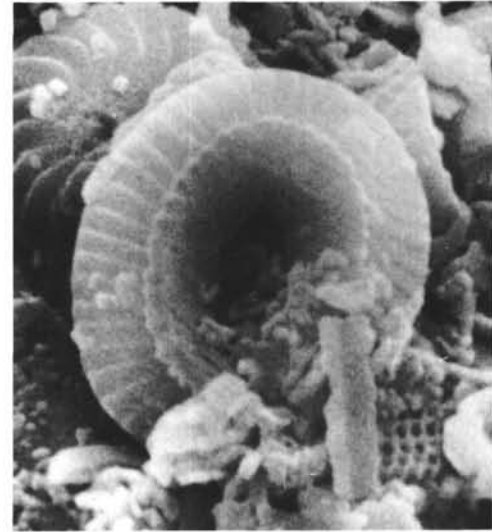


Plate 2. Quaternary nannofossils from Leg 85 sites. (SEM; magnification  $\times 6000$ .) 1-6. *Gephyrocapsa dornicoides* (1) var. 4, 573-2-5, 40 cm, (2) var. 1, distal side, 573-2-6, 40 cm, (3) var. 2, proximal side, 573-3-2, 40 cm, (4) var. 3, 573-3-3, 40 cm, (5-6) (lacunoid, 5, sample 573-2-7, 40 cm; 6, sample 573-4-5, 60 cm). 7. *Pseudoemiliana lacunosa*, elliptical type, 573-3-3, 40 cm. 8. *Helicopontosphaera kamptneri* s. ampl., 573-1-1, 40 cm. 9. *Helicopontosphaera sellii*, 573-4-5, 60 cm.

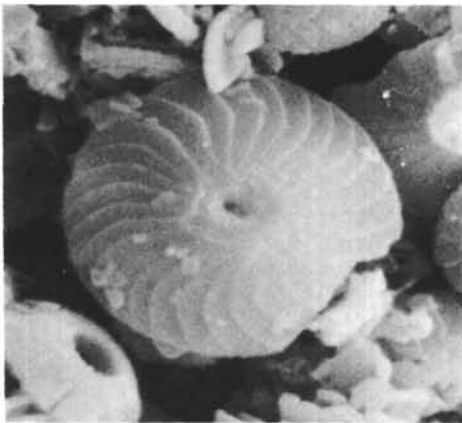


1

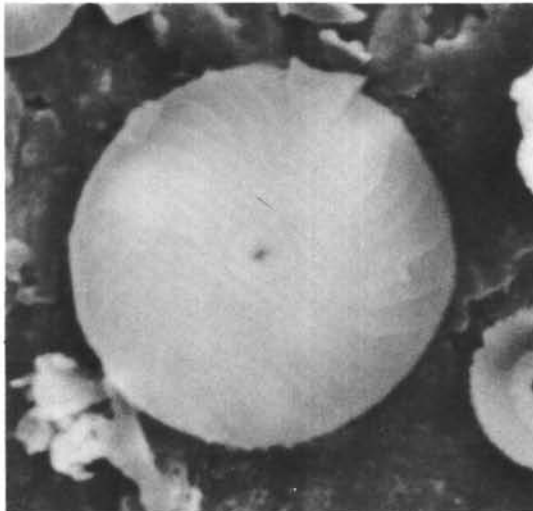
1.0  $\mu$ m



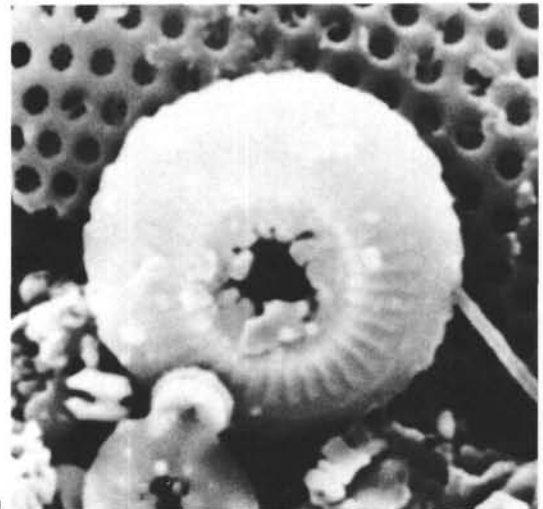
5



2



3



4

Plate 3. Quaternary nannofossils from Leg 85 sites (SEM; magnification  $\times 6000$ .) 1. *Cyclococcolithina leptopora* var. 1, distal side, 573-3-3, 40 cm. 2. *Cyclococcolithina leptopora* s. s., 573-3-3, 40 cm. 3. *Cyclococcolithina* sp. cf. *C. macintyreii*, 573-4-1, 120 cm. 4. *Cyclococcolithina macintyreii*, 573-4-5, 60 cm. 5. *Coccolithus pelagicus*, 573-4-5, 60 cm.