24. COMPARISON OF THE PLEISTOCENE RECORDS OF THE RADIOLARIAN *CYCLADOPHORA DAVISIANA* AT HIGH-LATITUDE SITES OF THE DEEP SEA DRILLING PROJECT[1]

Joseph J. Morley, Lamont-Doherty Geological Observatory of Columbia University[2]

ABSTRACT

The recovery from the North Atlantic (Site 611) of a continuous Pleistocene sedimentary record with a siliceous microfaunal component made it possible to compare the high-latitude abundance pattern of the radiolarian species *Cycladophora davisiana* in the Atlantic with that produced from analyses of a high-latitude record (Site 580) from the northwest Pacific. Previous studies had shown that the late Pleistocene (0–0.45 Ma) abundance variations of this species in these high-latitude regions were similar.

Cycladophora davisiana maxima in the North Atlantic record reach abundance levels three to four times higher than *C. davisiana* maxima registered in sediments from the northwest Pacific site. This difference in magnitude of abundance peaks is most likely an effect of the more northerly location of Site 611 (53°N) compared with that of Site 580 (42°N), since high-latitude time-slice studies have shown a direct relationship between increasing latitude and *C. davisiana* abundance. Discontinuous preservation of radiolarians in sediments from North Atlantic Site 611 allows only tentative correlation of the North Atlantic and northwest Pacific *C. davisiana* abundance curves. These correlations are confined to those portions of the cores where ages are tightly constrained by magnetic boundaries, and to intervals with comparable sedimentation rates.

INTRODUCTION

High-resolution stratigraphies derived from variations in calcium carbonate concentration or the ratio of ^{18}O to ^{16}O frequently cannot be constructed for high-latitude sites, because the sediments comprising many of these marine records do not contain sufficient amounts of calcium carbonate. Recent studies indicate that the abundance variations of the radiolarian species *Cycladophora davisiana* provides an excellent alternative stratigraphy in upper Pleistocene siliceous sediments. The percentage of this cosmopolitan species relative to all other radiolarians rarely exceeds 5% in Holocene sediments (Morley and Hays, 1983). In upper Pleistocene sediments from the Southern Ocean, the North Atlantic, and the northwest Pacific, however, *C. davisiana* abundance levels range from low values, similar to those recorded in Holocene sequences, to values above 40%. Correlation of this species' distinctive pattern with other stratigraphic records has shown that the relative abundance patterns of *C. davisiana* are synchronic over broad areas of the subantarctic (Hays et al., 1976), the North Atlantic (Morley and Hays, 1979; Morley, 1983), and the northwest Pacific (Morley et al., 1982). Further, the major features of the *C. davisiana* abundance patterns in upper Pleistocene sediments from these three widely separated regions are remarkably similar.

The recovery of a nearly continuous sedimentary record of the Pliocene/Pleistocene in the northwest Pacific during Leg 86 provided the opportunity to examine the C. *davisiana* abundance pattern in sequences older than 0.45 Ma. It was anticipated that a comparable record would be acquired from the North Atlantic because Leg 94 Site 611 is situated in one of the few regions of the North Atlantic where radiolarians are continuously present in piston cores containing sedimentary histories of the last 0.3 m.y. In this chapter the Pleistocene/Holocene abundance variations of *C. davisiana* at Site 611 in the North Atlantic and at Site 580 in the northwest Pacific are examined, and where possible, correlations are drawn between these two high-latitude records. The siliceous bio- and magnetostratigraphies for Site 580 and Site 611 for the Pleistocene are shown in Figure 1, with correlation lines connecting stratigraphic events common to both sites.

CYCLADOPHORA DAVISIANA ABUNDANCE PATTERN IN THE NORTHWEST PACIFIC

Site 580 was drilled in 5375 m of water at a position just north (41°38′N, 153°59′E) of today's Subarctic Front. Consisting of 154 m of siliceous clays and clayey diatom oozes, the sedimentary record from this site extends back almost 3.3 m.y., with an average sedimentation rate of over 50 m/m.y.

Figures 2 and 3 show the abundance pattern of *C. davisiana* at 30-cm intervals (~6000-yr. increments) in the uppermost 15 cores (135 m) from this site. Slides were prepared using the settling technique described by Moore (1973). With few exceptions, *C. davisiana* abundances in each sample were determined from a minimum count of 300 radiolarians. Because the hydraulic piston coring process did not always recover a complete 9.5-m section, the sedimentary records in some of the cores do not cover a full 9.5-m interval; unrecovered por-

[1] Ruddiman, W. F., Kidd, R. B., Thomas, E., et al., *Init. Repts. DSDP*, 94: Washington (U.S. Govt. Printing Office).

[2] Address: Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964.

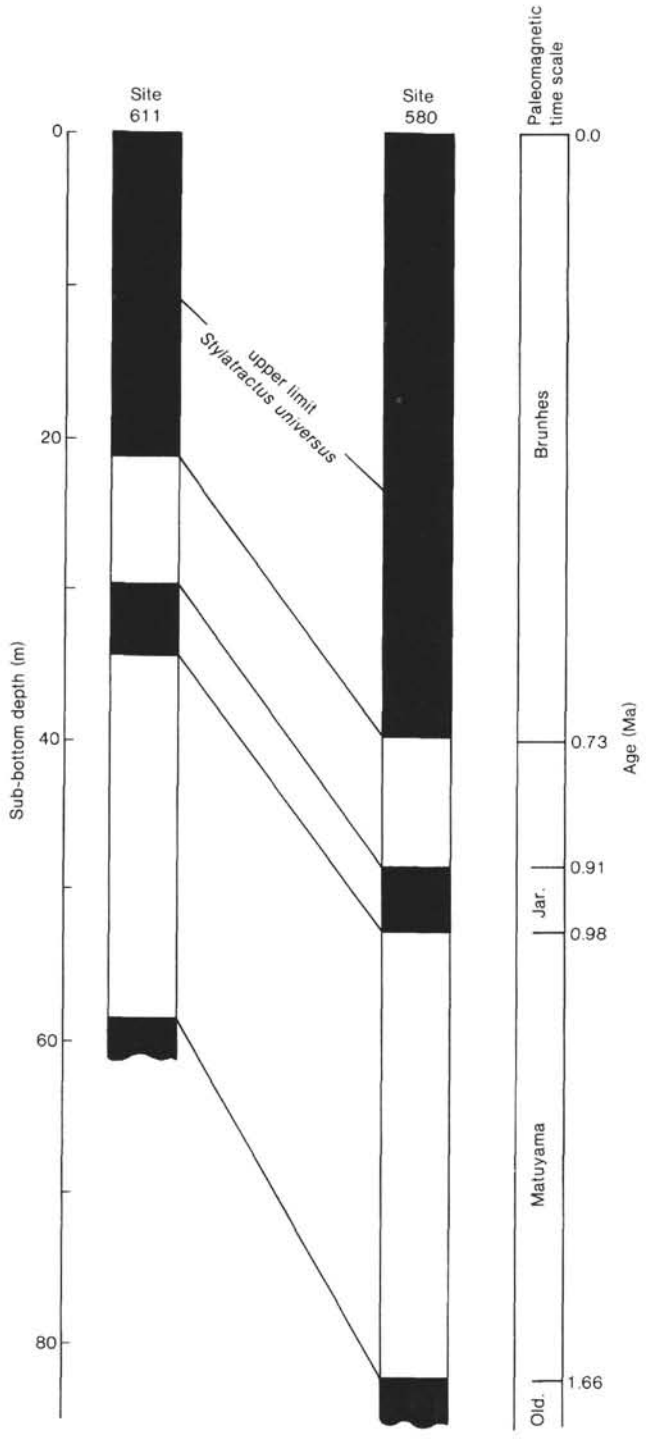

Figure 1. Comparison of Pleistocene magnetostratigraphy and siliceous biostratigraphy at northwest Pacific Site 580 with counterparts at North Atlantic Site 611. Lines drawn between two columns connect stratigraphic events common to both sites.

tions are represented as missing data at the bottom of the appropriate cores. In the portion of the *C. davisiana* curve for Site 580 that is comparable to the one reported for the northwest Pacific piston-core records (0–0.45 Ma), maxima and minima in the *C. davisiana* abundance pattern have been labeled with an alphabetical identifier beginning with the Holocene low-abundance zone. The prime superscript preceding each letter designation differentiates the northwest Pacific *C. davisiana* curves from their subantarctic and North Atlantic counterparts. Despite the small data gaps at the bases of some cores from Site 580, the combination of magneto-, tephra-, and biostratigraphy enables one to identify (letter designations) distinct maxima and minima in the upper 24 m of this core which correspond to similar features in northwest Pacific long piston-core records with relatively high sedimentation rates (>30 m/m.y.) (Morley et al., 1982).

In Cores 580-1 through 580-12, no distinction was made between the three distinct subspecies of *C. davisiana*, as defined by Petrushevskaya (1967). Analyses by Morley (1980) have shown that the total abundance of two of the three variants of *C. davisiana* rarely exceeds 3% of the total radiolarian fuana in upper Pleistocene sequences; the abundances of the subspecies *C. davisiana davisiana* account for most of the high-latitude Pleistocene abundance variations in *C. davisiana*. Chen (1975) reported the first subantarctic appearance of *C. davisiana davisiana* in the Pliocene between 2.5 and 2.9 Ma; the other subspecies of *C. davisiana* first appeared much earlier. To document this event at Site 580, the abundance of *C. davisiana davisiana* in cores 580-13 through 580-15 was plotted separately (dashed line), in addition to the curve representing the abundance of all three subspecies (solid line). The data from Site 580 indicate that *C. davisiana davisiana* first appeared in northwest Pacific waters at approximately 2.58 Ma, in the upper Gauss Epoch (sub-bottom depth of 128.5 m). The other two subspecies of *C. davisiana* (*C. davisiana cornutoides* and *C. davisiana semeloides*) first appeared in the northwest Pacific earlier in the Tertiary.

Morley (1983) and Morley and Hays (1983) have hypothesized that high abundances (>20%) of *C. davisiana* in high-latitude upper Pleistocene marine sediments reflect prolonged periods of sea-ice cover, increased levels of sea-ice and/or iceberg melt water producing low-salinity surface waters in summer/fall, and the establishment of a year-round shallow temperature minimum, with relatively stable temperatures and salinities at depths below this minimum. Although *C. davisiana* abundances at Site 580 rarely exceed 20% of the total radiolarian fauna, *C. davisiana* abundance maxima exceed 10% on a regular basis above a sub-bottom depth of 110 m (~2.2 Ma). Assuming that the oceanographic conditions associated with high abundances of *C. davisiana* did not change throughout the Pliocene/Pleistocene, it would appear that oceanographic properties at Site 580 during the most recent glaciation (coinciding with *C. davisiana* maxima $'b_1$ and $'b_2$) have been recurring at this latitude in the northwest Pacific periodically for at least the last 2.2 m.y.

CYCLADOPHORA DAVISIANA ABUNDANCE PATTERN IN THE NORTH ATLANTIC

At Site 611, sediment samples were obtained from the eastern flank of the Mid-Atlantic Ridge (52°51′N, 30°19′W), in a region (Gardar Drift) characterized by relatively high accumulation rates (water depth 3204 m). The upper 114 m of the 125 m of sediment cored at both

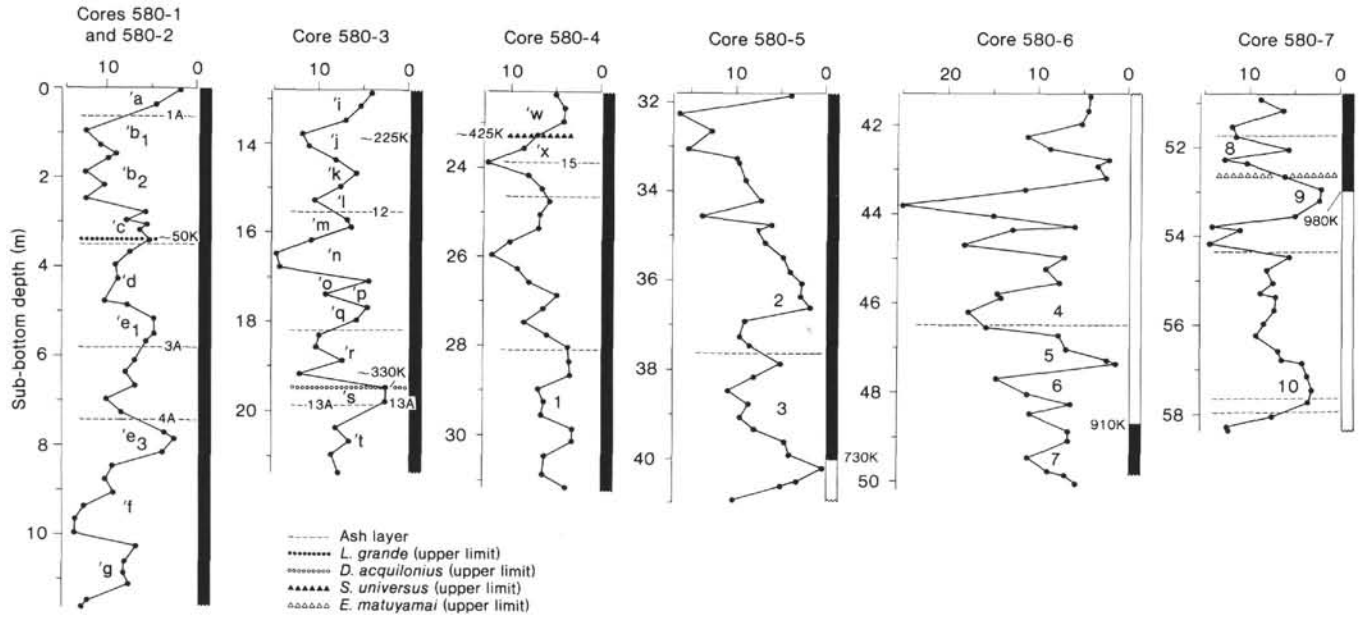

Figure 2. Percent *C. davisiana* relative to total radiolarian fauna in first seven cores from DSDP Hole 580. Sub-bottom depth (meters) in each core is shown in column at left of each curve; magnetostratigraphy is shown in column at right of each curve.

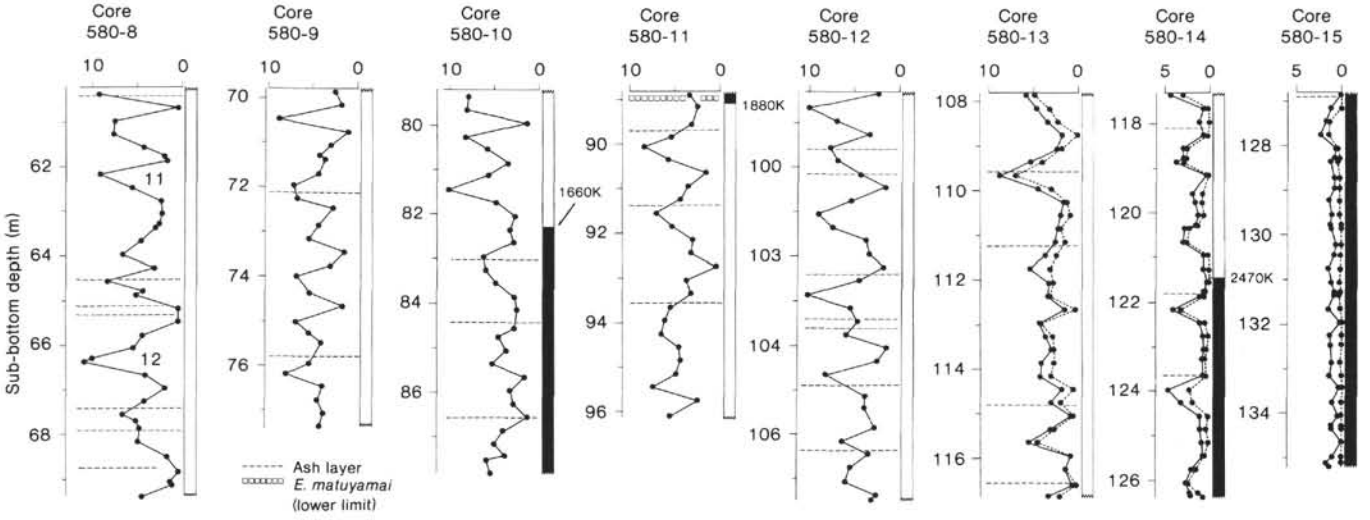

Figure 3. Percent *C. davisiana* relative to total radiolarian fauna in Cores 8 through 15 from DSDP Hole 580. Sub-bottom depth (meters) in each core is shown in column at left of each curve; magnetostratigraphy is shown in column at right of each curve. In cores 13 through 15, the abundance of subspecies *C. davisiana davisiana* (dashed line) is plotted in addition to the curve representing abundance of all three subspecies of *C. davisiana* (solid line).

Hole 611 and Hole 611A consists of interglacial foraminiferal nannofossil oozes alternating with glacial calcareous muds. On the basis of the magnetostratigraphy from Hole 611 (Clement and Robinson, this volume), the sedimentation rate for the Pleistocene averaged 35 m/m.y. (Table 1).

Slides were prepared from samples taken at approximately 25-cm intervals (~7000-yr. increments), using the methods previously described for Site 580 samples. Because radiolarian preservation was so poor in the upper portion of Hole 611 (Cores 611-1 and 611-2), additional samples from Core 611A-1 were examined. Figure 4 shows the abundance of *C. davisiana* relative to all other radiolarian fauna in all slides containing sufficient radiolarians. Dashed lines indicate intervals where radiolarians were not present in samples analyzed. As with sediment cored at Site 580, incomplete recovery of sediment in most cores results in a small data gap at the base of each

Table 1. Sedimentation rates of Pleistocene/Holocene sequences from northwest Pacific Site 580 and North Atlantic Site 611.

Magnetostratigraphic boundary	Age (Ma)	Site 580		Site 611	
		Depth (m) of boundary	Sedimentation rate (m/m.y.)	Depth (m) of boundary	Sedimentation rate (m/m.y.)
Brunhes/Matuyama	0.73	40.00	54.8	20.13	27.6
Matuyama/Jaramillo	0.91	48.70	48.3	29.73	53.3
Jaramillo/Matuyama	0.98	53.03	61.9	34.53	68.5
Matuyama/Olduvai	1.66	82.33	43.1	58.53	35.3

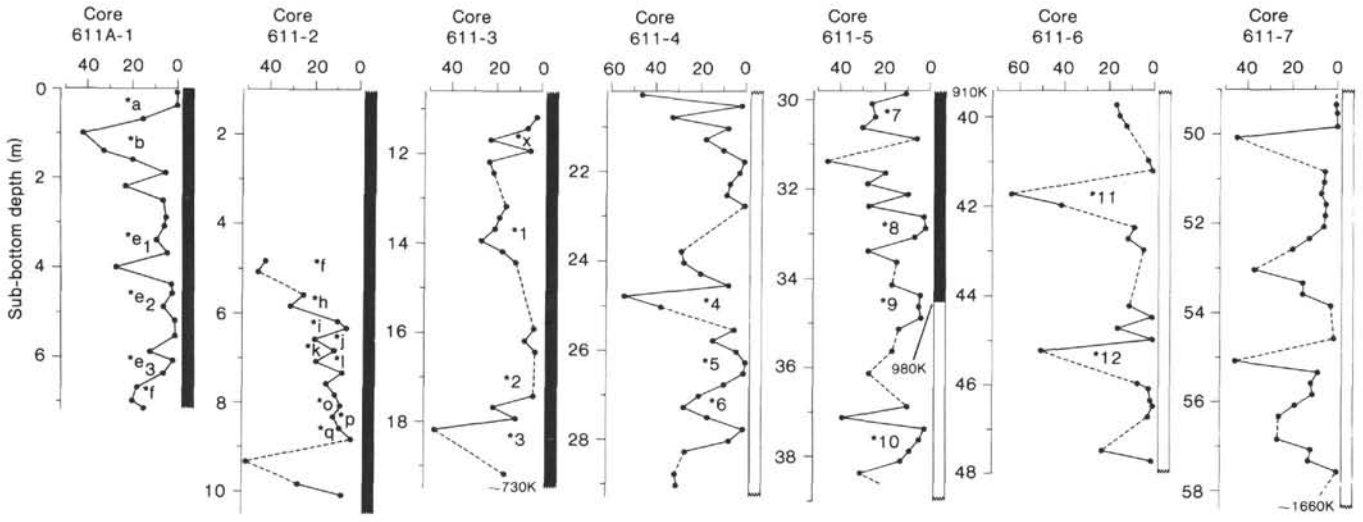

Figure 4. Percent *C. davisiana* relative to total radiolarian fauna in Core 1 from DSDP Hole 611A and Cores 2 through 7 from DSDP Hole 611. Sub-bottom depth (meters) in each core is shown in column at left of each curve; magnetostratigraphy is shown in column at right of each curve. Dashed-line segments of abundance curves designate intervals where radiolarians were not present in prepared samples.

core. The Pleistocene/Holocene sequence in Core 611A-1 has been appended to the Pleistocene record from Hole 611 (Cores 611-2 through 611-7), with the base of Core 611A-1 corresponding to the interval between 4 and 5 m sub-bottom in Core 611-2.

Various maxima and minima in the *C. davisiana* pattern at Site 611 have been given letter designations indicating their tentative correlation with late Pleistocene/Holocene (0–0.45 Ma) *C. davisiana* abundance patterns in piston cores from the North Atlantic. The asterisk superscript preceding the letter designation signifies that the *C. davisiana* record was derived from North Atlantic marine sediments. On the basis of this tentative correlation, the *C. davisiana* abundance pattern in Core 611A-1 coincides with the upper 6 m of the *C. davisiana* record in piston core V27-116 (Morley and Hays, 1979), taken within a minute of latitude and longitude of this site (Fig. 5). The abundance curves for V27-116 and Hole 611A both contain a low-abundance level (*a) at the core top, coinciding with the Holocene/uppermost Pleistocene, overlying a high-abundance zone (*b) which represents the latter stages of the last glacial period. The sediment history of the last full interglacial, coinciding with *C. davisiana* abundance levels $*e_1$ through $*e_3$, is recorded at core depths between 3 and 6 m in both cores. The letter designations given for *C. davisiana* maxima and minima in Cores 611-2 and 611-3 are more provisional than those given for *C. davisiana* abundance levels in Core 611A-1, because of intermittent radiolarian preservation (dashed lines), which occurs throughout the sediment sequence from Hole 611. The last appearance of the radiolarian species *Stylatractus universus*, in the upper meter of Core 611-3, provided stratigraphic control for identifying specific *C. davisiana* maxima and minima around this event. Data presented by Hays and Shackleton (1976) and Morley and Shackleton (1978) indicate that this datum level is globally synchronic, coinciding with the transition between oxygen isotope stages 12 and 11.

COMPARISON OF NORTHWEST PACIFIC AND NORTH ATLANTIC *C. DAVISIANA* PATTERNS

Difficulties arise in attempting to correlate the *C. davisiana* pattern for the entire Pleistocene in the northwest Pacific with that recorded in the North Atlantic. The *C. davisiana* pattern is not continuous in either high-latitude region, because of the data gaps that exist at the bases of many of the cores as a result of incomplete sediment recovery. The North Atlantic record has the additional problem of intermittent radiolarian preservation, which creates discontinuities of various lengths (dashed lines in Fig. 4) in all the cores from Hole 611. It is difficult to assess the precise effect of the wide variations in silica preservation on the North Atlantic *C. davisiana* abundance curve. Although specific radiolarian species may be more resistant to silica dissolution than others, I have found from qualitative analyses that the degree of resistance does not appear to vary widely between individual species. Therefore, although variations in the degree of silica dissolution may cause minor variations in the character of the *C. davisiana* curve, these are not enough to distort completely the *C. davisiana* abundance pattern. These problems make it impossible to correlate every *C. davisiana* peak in the North Atlantic with its counterpart in the northwest Pacific, but it is possible to compare the *C. davisiana* abundance curves for the two ocean regions in sections of the cores near magnetic boundaries, and through intervals with comparable sedimentation rates. Accordingly, maxima and minima which appear to be common to the *C. davisiana* pattern in the portions of both the North Atlantic and the northwest Pacific records older than 0.45 Ma have been assigned specific numbers (Figs. 2–4). Six of these 12 numbered *C. davisiana* levels occur between the Brunhes/Matuyama and Jaramillo/Matuyama boundaries (0.73–0.98 Ma), a time interval over which the sedimentation rates were similar at both sites (Table 1).

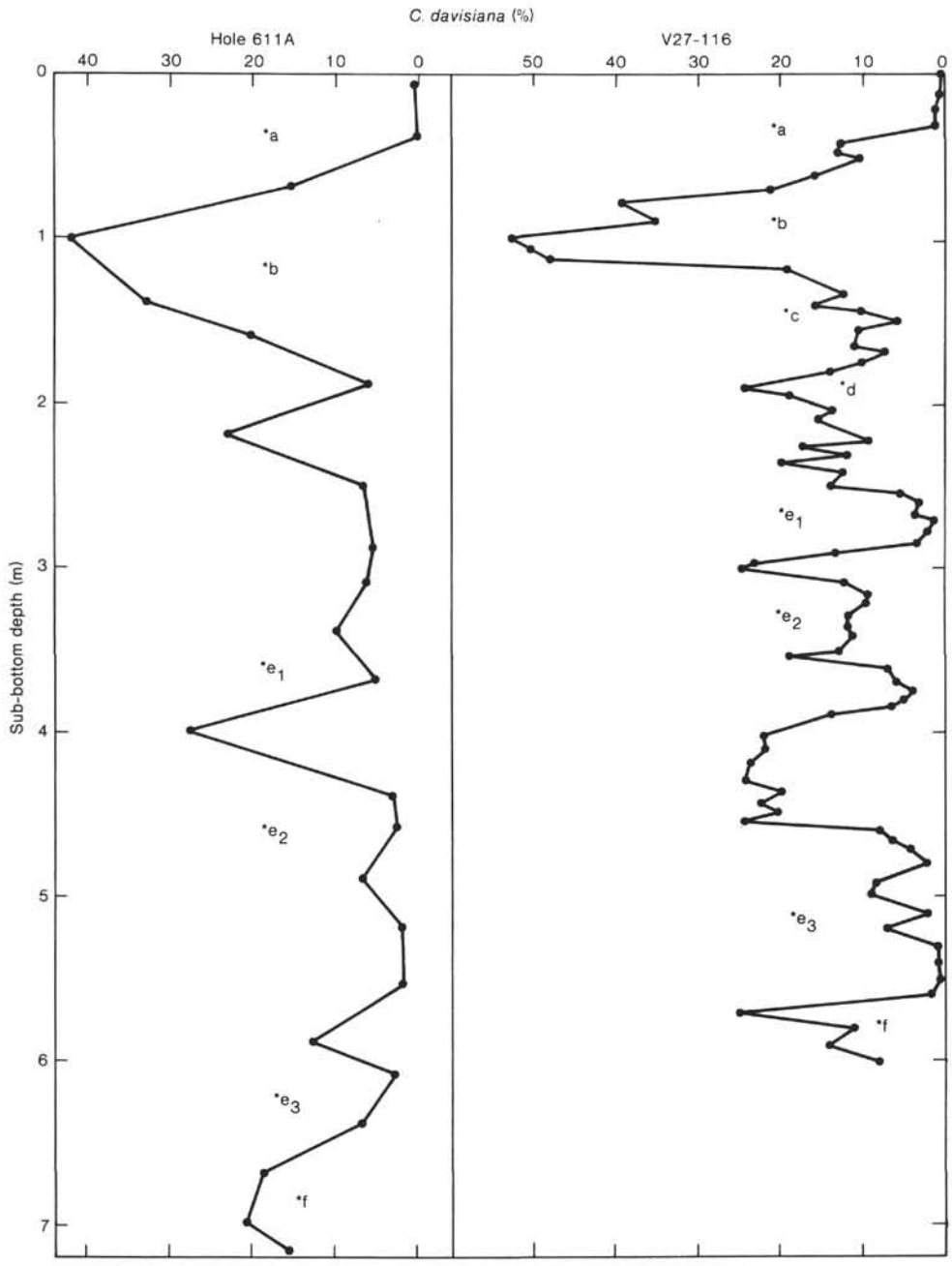

Figure 5. Percent *C. davisiana* relative to total radiolarian fauna in Core 1 from DSDP Hole 611A, compared with *C. davisiana* abundance pattern in North Atlantic piston core V27-116.

The individual *C. davisiana* maxima in the North Atlantic record frequently exceed 40% of the total radiolarian fauna, whereas maxima in the northwest Pacific range between 10 and 15% throughout the Pleistocene. Morley (1983) recognized that the percentage of *C. davisiana* of specific abundance maxima increased with increasing latitude in the North Atlantic, with *C. davisiana* in sediment sequences south of 45°N rarely exceeding 20%, whereas maxima in cores north of 55°N reached values over 60%. Analyses of radiolarians at the last glacial maximum in the northwest Pacific (Robertson, 1975) also showed a general increase in *C. davisiana* abundance from southeast to northwest. From these results, it would appear that the specific oceanographic conditions advantageous to *C. davisiana* are enhanced with increased latitude during the time of *C. davisiana* maxima. Therefore, the lower *C. davisiana* abundance levels of specific maxima in the Pacific record, compared with those in the North Atlantic curve throughout the Pleistocene, most likely result from the lower latitude of the northwest Pacific site relative to the North Atlantic Site (41°38′N vs. 52°51′N). Oceanographic conditions as-

sociated with the high-latitude *C. davisiana* maxima were not quite as pronounced at Pacific Site 580 as at North Atlantic Site 611.

CONCLUSIONS

Intermittent preservation of radiolarians in sediments from North Atlantic Hole 611 made it difficult to compare each major maximum and minimum in the *C. davisiana* abundance pattern for the entire Pleistocene with the maxima and minima recorded over the same period at northwest Pacific Site 580. Specific maxima in the North Atlantic record, tentatively correlated with maxima in the northwest Pacific *C. davisiana* pattern, reached abundance levels three to four times higher than their northwest Pacific counterparts. This difference in magnitude of *C. davisiana* maxima is attributed to the higher latitude of the North Atlantic site. At both Site 580 and Site 611, *C. davisiana* undergoes abundance variations throughout the Pleistocene which are similar in magnitude to those recorded during the latter stage of the last glacial period. This indicates that the oceanographic conditions associated with these high abundance levels occurred periodically throughout the Pleistocene at similar levels of intensity/severity.

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