

## Late Pliocene calcareous nannofossil paleobiogeography of the Pacific Ocean: evidence for glaciation at 2.75 Ma

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### ABSTRACT

Calcareous nannofossil assemblages from land sections of the Japanese Islands and DSDP Holes in the equatorial to high latitude regions of the Pacific Ocean were analyzed in an effort to reconstruct their late Pliocene paleobiogeography. While the late Pliocene assemblages in the equatorial to middle latitude regions are comprised primarily of discoasters, both the high latitude and Japan Sea samples record an abrupt change from a *Reticulofenestra-Dictyococcite* assemblage to a *Coccolithus pelagicus* assemblage at 2.75 Ma. The northernmost boundary of the Discoaster assemblage moved southward in the East China Sea (western Pacific Ocean) at that time. These changes in the calcareous nannofossil paleobiogeography indicate the strong influence of heavy glaciation in high latitude to arctic regions of the Pacific Ocean. This also correlates with the final closure of the Central American seaway at 2.75 Ma.

Keywords: Pliocene, calcareous nannofossil, paleobiogeography, Pacific Ocean, glaciation.

### RESUMEN

Se analizan conjuntos nanofosiles calcáreos de secciones terrestres de las Islas Japonesas y de Sitios del DSP, desde regiones ecuatoriales hasta altas latitudes del Océano Pacífico, en un esfuerzo para reconstruir su paleobiogeografía correspondiente al Plioceno tardío. Mientras que los conjuntos del Plioceno tardío en las regiones ecuatoriales y de latitud media están compuestos principalmente de Discoasteracea, las muestras provenientes del Mar de Japón registran un cambio abrupto de un conjunto *Reticulofenestra-Dictiococcita* a un conjunto *Coccolithus pelagicus*, a 2.75 Ma. El límite más septentrional del conjunto Discoasteracea se desplazó hacia el sur en el Mar de China (Pacífico Occidental) en ese tiempo. Estos cambios en la Paleobiogeografía de los nanofósiles calcáreos indican una fuerte influencia de glaciación severa en las regiones de alta latitud y hacia el ártico del Océano Pacífico. Esto se correlaciona también con el cierre final de la vía marítima de América Central ocurrida a 2.75 Ma.

Palabras clave: Plioceno, nanofosiles calcáreos, paleobiogeografía, Océano Pacífico, glaciación.

## INTRODUCTION

Calcareous nannofossils, which have been widely distributed in the world's oceans since the Mesozoic, are well known as a useful tool for paleoenvironmental analysis as well as for age determination. Haq (1980) already analyzed the Miocene calcareous nannofossil assemblages in the Atlantic Ocean and clarified the paleobiogeography. Furthermore, Kameo and Sato (2000) also discussed the timing of the final elevation of the Isthmus of Panama based on the calcareous nannofossil paleobiogeography around Central America, and concluded that the final closure of the Isthmus of Panama occurred at 2.75 Ma based on the disappearance in similarities of the calcareous nannofossil assemblages between the Caribbean and the eastern equatorial Pacific regions.

Late Pliocene to Quaternary calcareous nannofossil assemblages were collected from DSDP-ODP holes in the equatorial to high latitude regions of the Pacific Ocean and from land sections on the Japanese Islands. The goal of this study was to reconstruct the late Pliocene calcareous nannofossil paleobiogeography and paleoceanography around 2.75 Ma in the Pacific Ocean,

which was related to the final closure of the Isthmus of Panama.

## SAMPLES AND METHOD

Samples from nine DSDP-ODP holes located in the equatorial to high latitude region of the Pacific Ocean were examined. Additionally, samples from three land sections on the Japanese Islands, and one oil well on the offshore Pacific side of Japan were studied (Figure 1). Each sample was processed according to the method outlined by Stradner and Papp (1961). Approximately 5 g of core material was stirred into about 20 mL of water in a small beaker. After the heavier particles had settled, approximately 1 mL of water was withdrawn with a straw from the upper layer of the suspension, and placed on a microscopic cover glass (24 mm x 24 mm). The liquid was allowed to dry on an electric hot plate set at 40 °C. A drop of Enthellan New was spread over the center of a microslide onto which the cover glass was pressed upside down. After the mounting reagent had hardened completely, the microslide was observed under an Olympus Binocular Polarizing Microscope (BX-P)

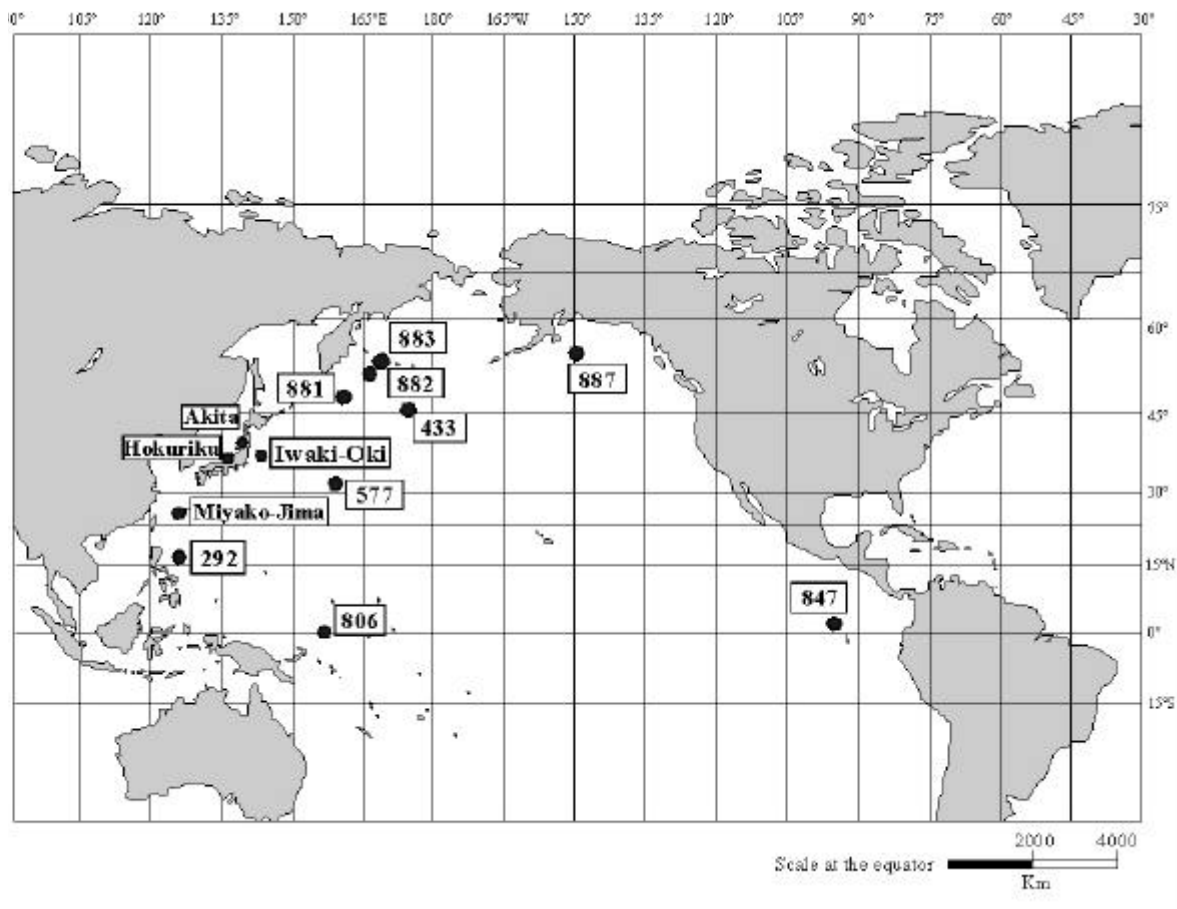


Figure 1. Location map of the DSDP-ODP Holes, oil well, and land section analyzed in this study.

with an oil-immersion objective at a magnification of 1,500x. Emphasis was placed on the quantitative analysis of the distribution of each species throughout the uppermost Cenozoic sequences.

### PLIOCENE TO PLEISTOCENE NANNOFOSSIL DATUMS

Based mainly on the analysis of deep sea cores, many Pliocene to Pleistocene calcareous nannofossil events have been clarified in recent studies (Gartner, 1977, and others). In 1987, Takayama and Sato recognized 12 calcareous nannofossil datums in the Quaternary sediments recovered from Deep Sea Drilling Project Leg 94 (North Atlantic). Ages for all datums were estimated by interpolation between magnetic reversals. Subsequently, the relationship between magnetic reversals and the calcareous nannofossil datums was summarized by Sato *et al.* (1991). They found 21 datums in the upper Pliocene to Pleistocene sequence and numbered them from one to twenty-one in descending stratigraphic order. Recently, Sato *et al.* (1999) recalculated the ages of those calcareous nannofossil datums based on new magnetochronology by Cande and Kent (1995). Sato and Kameo (1996) discussed Pliocene to Pleistocene

nannofossil datum planes in sediments collected from the Arctic Ocean during ODP Leg 151 (Sites 910 and 911). They showed that the Pleistocene datums defined by Takayama and Sato (1987) were applicable to the Arctic Ocean, as well. However, Pliocene marker species of the genus *Discoaster* which occur abundantly in low latitudes were not found in the arctic region. Instead, Sato and Kameo (1996) recognized a new nannofossil datum (Datum A) which is related to late Pliocene heavy glaciations in high latitude regions (2.78 Ma; late Gauss Normal Epoch). They discussed the relationship between Datum A and those described by Sato *et al.* (1991) and showed the possibility that Datum A may correlate with Datum 18 (last appearance datum of *Discoaster tamalis*; 2.75 Ma). Maslin *et al.* (1996) suggested that the Eurasian Arctic and Northeast Asia were significantly glaciated from 2.75 Ma onward. Therefore, in the present study, we have assumed the age of Datum A to be 2.75 Ma.

Figure 2 shows the revised ages of the calcareous nannofossil datums of Sato *et al.* (1991) and Datum A in the Arctic Ocean (Sato and Kameo, 1996). Based on these datums, we will describe and discuss the Pliocene to Pleistocene calcareous nannofossil assemblages of the Pacific Ocean in an attempt to clarify the calcareous nannofossil paleobiogeography.

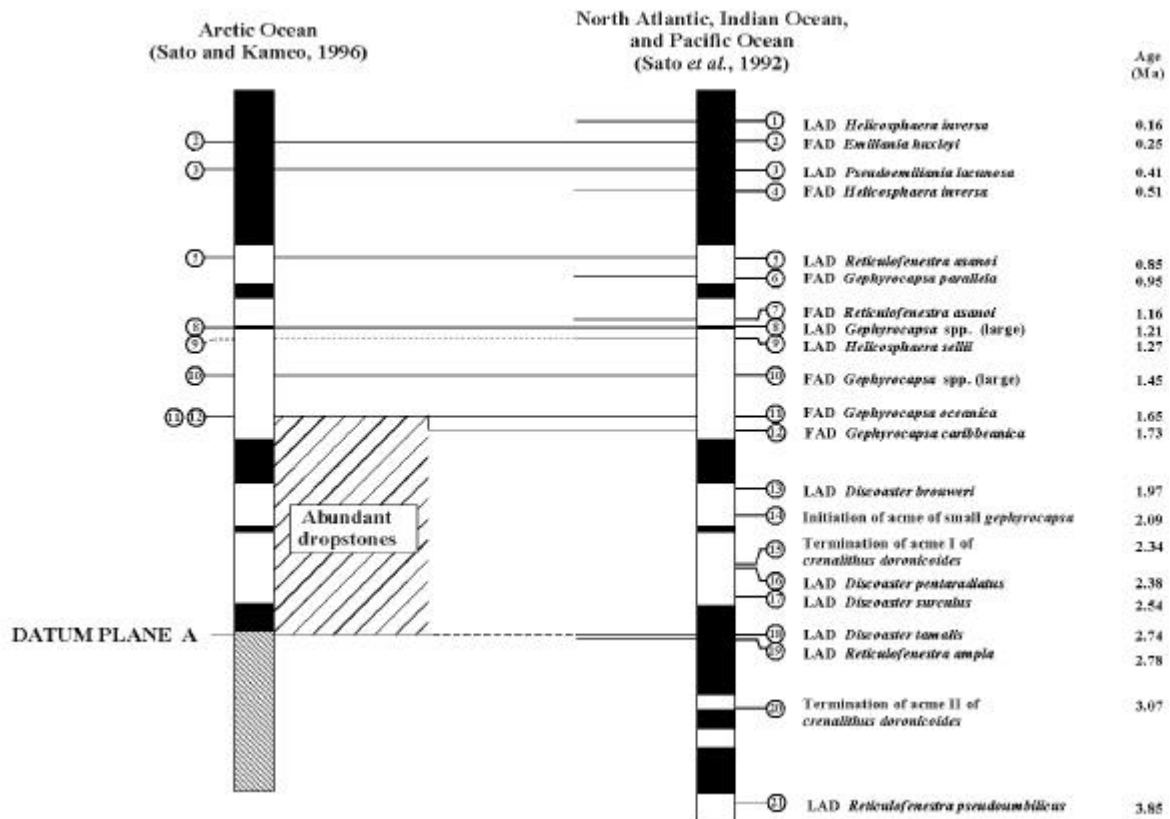


Figure 2. Calcareous nannofossil datum planes recognized in the Arctic Ocean with reference to nannofossil datums of Sato *et al.* (1992).

## CALCAREOUS NANNOFOSSIL ASSEMBLAGES OF THE UPPERMOST CENOZOIC IN THE PACIFIC OCEAN

### Equatorial Pacific

Kameo and Sato (2000), Takayama (1993) discussed the calcareous nannofossil assemblages related to paleoclimatology in ODP Holes 806 and 847 located in the equatorial Pacific Ocean. Because the assemblages found in these holes are characterized by high species diversity including the late Pliocene to Quaternary marker species of Takayama and Sato (1987) and Sato et al. (1988), twenty-one datum planes are easily recognized in these two holes. The nannofossil assemblages are characterized by the abundant occurrences of the warm water genus *Discoaster* with the cold water species *Coccolithus pelagicus* being rare or absent throughout the Pliocene sequences. Warm water species are more abundant in the western equatorial Pacific Ocean than in the eastern equatorial Pacific. The upper Pliocene sequence in DSDP Hole 292A, located in the western Philippine Sea, is composed of nannochalk. Abundant, well-preserved nannofossils occur throughout the section. Small *Reticulofenestra*, *Pseudoemiliana* and *Discoaster* are abundant in the upper Pliocene, while small *Gephyrocapsa* dominate the Quaternary sediments (Figure 3). Pliocene datum planes 13, 16, 17, 18, and 21, defined by last occurrences of discoasters and sphenoliths, and Quaternary datums 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 are easily detected in the section (Figure 3). The warm water nannofossil *Discoaster* makes up 25% to 50% of the assemblage between Datum 18 (2.75 Ma) and Datum 21 (3.66 Ma). The abundance of *Discoaster* decreases above Datum 18. *Coccolithus pelagicus* is rare to absent throughout the section.

### Middle latitude region of the Pacific

DSDP Hole 577A and the Iwaki–Oki well are located in this region. The calcareous nannofossil assemblages from the Iwaki–Oki well, which is located on the offshore Pacific side of Japan, were discussed by Kameo and Sato (1999). *Discoaster brouweri*, *D. pentaradiatus*, *D. surculus*, and *D. tamalis*, which define the nannofossil datum planes 13, 16, 17, and 18, respectively, are easily detected in the upper Pliocene section. The cold water nannofossil *Coccolithus pelagicus* occurs rarely, but continuously, throughout the Pliocene interval. The calcareous nannofossils found in Hole 577A exhibit high species diversity. The assemblages are dominated by small *Reticulofenestra* and small *Dictyococcites* which together represent 80% of the total assemblage throughout the core. Upper Pliocene datums 13, 16, and 17, which are based on the stratigraphic distribution of warm water genus *Discoaster*, are easily recognized in the section (Figure 4).

### High latitude region of the Pacific

The Pliocene to Quaternary nannofossil assemblages from the high latitude region of the Pacific Ocean are very similar to those found in the Arctic Ocean with the exception of DSDP Hole 433A, located on the Suiko Seamount. Samples from DSDP Hole 433A and ODP Holes 881B and D, 882A, 883C, and 887A (Figure 1) were analyzed. The calcareous nannofossil biostratigraphy of Hole 433A was discussed by Takayama (1980). We re-examined the calcareous nannofossil assemblages in samples from cores 2 and 3. The warm water species *Discoaster brouweri*, *D. pentaradiatus*, *D. surculus*, *D. asymmetricus*, and *D. tamalis* occur in the upper Pliocene sequence in core 3 to the upper part of core. The Pleistocene marker species *Gephyrocapsa caribbeanica* and *G. oceanica* are found in sample 433A–2–1, 100–101 cm. Based on these facts, the upper Pliocene to Quaternary datum planes 11, 12, 13, 16, 17, and 18 are traceable in the sequence between 433A–2–1, 100–101 cm and 2–1, 122–123 cm. This indicates a hiatus of about 1.1 million years interval (from 2.75 Ma to 1.65 Ma).

The calcareous nannofossil assemblages in Hole 881B, located near Kamchatka, are characterized by rare specimens and low species diversity. Although *Coccolithus pelagicus* is common, discoasters are missing from the Pliocene section.

Nannofossils in Hole 882A, also located near Kamchatka, also exhibit low species diversity. However, the abundance is greater than in Hole 881B. The quantitative analyses of nannofossil assemblages in Hole 882A are shown in Figure 5. Discoasters are rare in the sequence. Therefore, the upper Pliocene nannofossil datums defined by the lineage of discoasters, are not recognizable in this sequence. The assemblage found in the upper Pliocene sequence is similar to those found in the Arctic Ocean (Sato and Kameo, 1996). Assemblages in the sequence below 117 mbsf are characterized by abundant *Reticulofenestra* spp. and *Dictyococcites* spp. and common *Coccolithus pelagicus*. *Coccolithus pelagicus* was highest in abundance above 117 mbsf. Therefore, Datum A, which was first recognized in the Arctic Ocean (Sato and Kameo, 1996; 2.75 Ma), is traceable to 117 mbsf in this hole.

Nannofossils in ODP Hole 883C were discussed by Sato et al. (1998). That assemblage is also similar to Hole 882A. Although no discoasters were found in the Pliocene section, eight Quaternary datum planes described by Takayama and Sato (1987) are detectable (Figure 6). The upper Pliocene section above 95 mbsf is characterized by abundant *Coccolithus pelagicus*. Therefore, Datum A is situated within this depth.

The uppermost Cenozoic sediments in ODP Hole 887A are characterized by low species diversity (Figure 7). The assemblages are dominated by *Dictyococcites* spp. and *Reticulofenestra* spp. in the lower half of the section, and by *Coccolithus pelagicus* in the upper part of the upper Pliocene to Quaternary section.

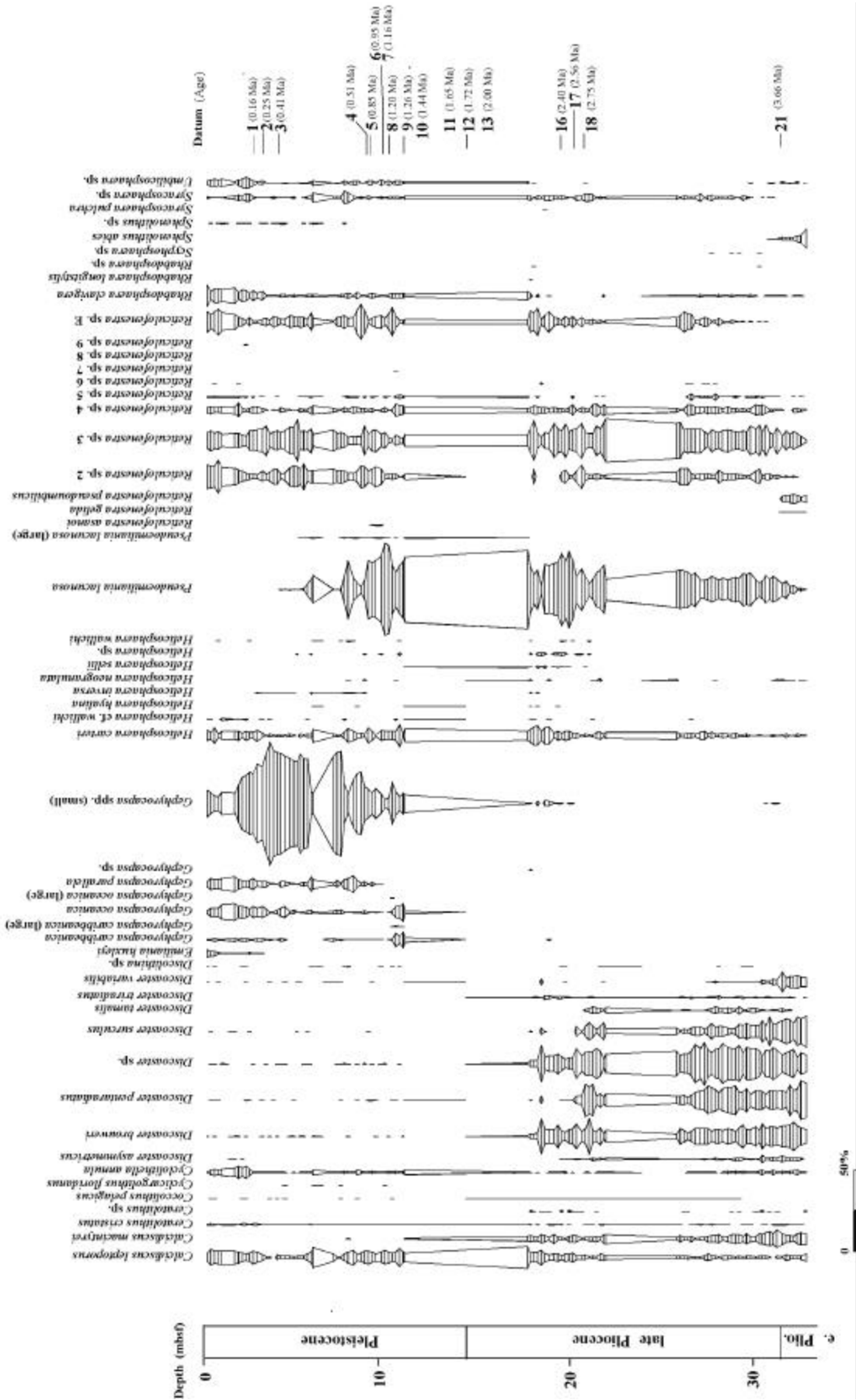


Figure 3. Stratigraphic distribution of calcareous nannofossil species in Hole 292A located in the Philippine Sea.

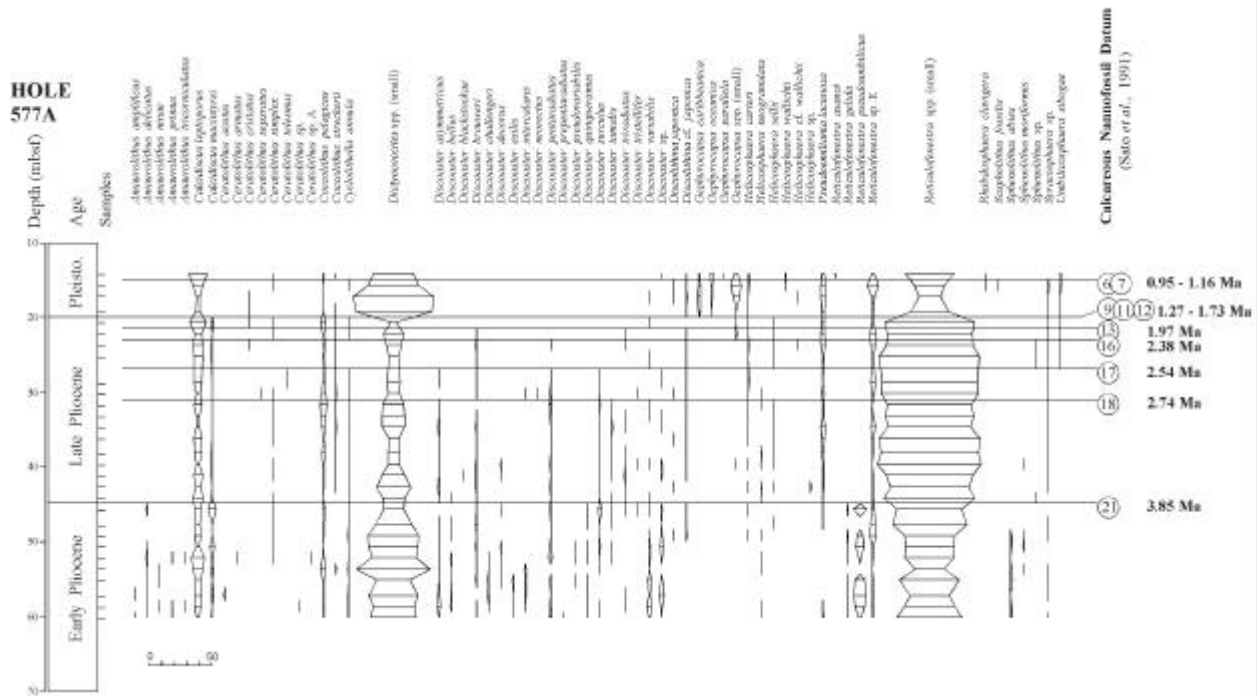


Figure 4. Stratigraphic distribution of calcareous nannofossil species in Hole 577A located in middle latitude of the Pacific Ocean.

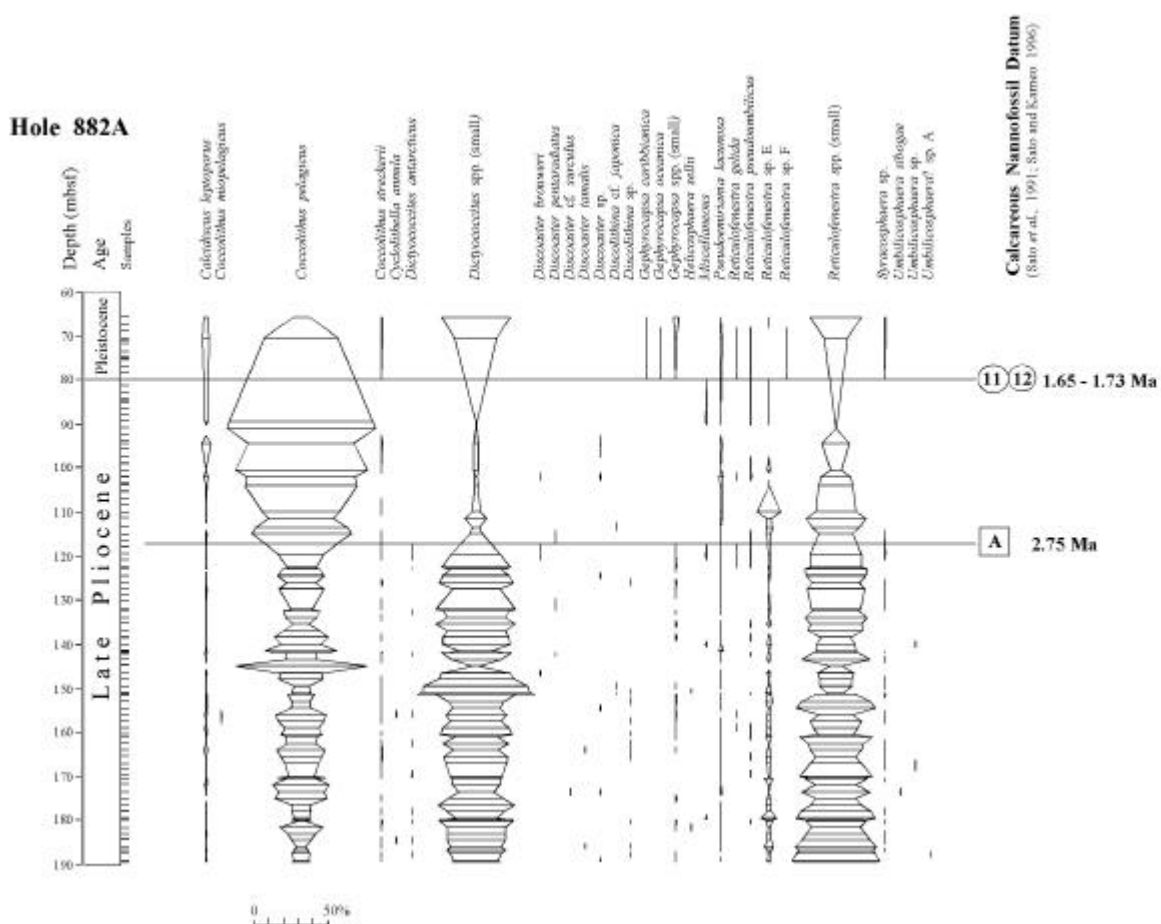


Figure 5. Stratigraphic distribution of calcareous nannofossil species in Hole 882A located in high latitude of the Pacific Ocean.

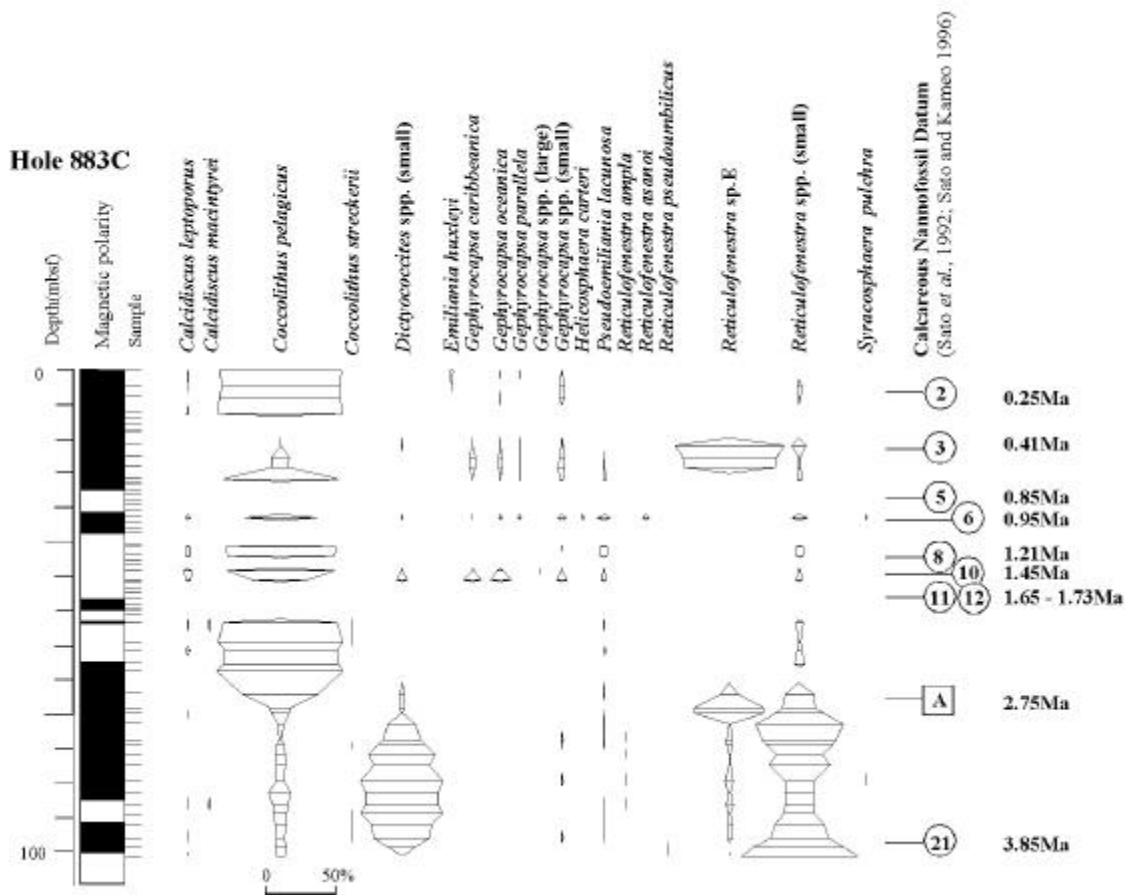


Figure 6. Stratigraphic distribution of calcareous nannofossil species in Hole 883C located in high latitude of the Pacific Ocean (Magnetic polarity: Weeks *et al.*, 1995).

Datum A is traceable to 90 mbsf in the upper Pliocene section (Figure 7).

### Japanese Islands

Miyako–Jima Island, which is located in the southern part of Japan, is one of the Ryukyu Islands. The Pliocene Yonahama and Minebari Formations, which consist of siltstone or alternating siltstone and fine sandstone, are widely distributed on the island. Calcareous nannofossil assemblages from the Yonahama and lower Minebari Formations are characterized by abundant warm water discoasters and sphenoliths (Figure 8). However, all discoasters, including the Pliocene marker species *D. tamalis*, *D. surculus*, and *D. pentaradiatus*, have their last occurrence in the lower part of the Minebari Formation. The last occurrence of *Reticulofenestra ampla*, which correlates to the lower part of the upper Pliocene (2.78 Ma), is also recognized in this horizon. Above this level, the calcareous nannofossil assemblages, which show low species diversity, are characterized by abundant *Reticulofenestra* spp. and *Coccolithus pelagicus*.

The drastic change from a Discoaster dominated assemblage to the *Coccolithus pelagicus* assemblage is very similar to that found in the Arctic Ocean. Therefore, the horizon marked by the drastic floral change from discoasters to *Coccolithus pelagicus* and the last occurrence of *Reticulofenestra ampla* is correlated to Datum plane A (2.75 Ma).

The Pliocene to Quaternary nannofossils of the Akita and Hokuriku area located on the Japan Sea side of Japan (Figure 1), were discussed by Sato *et al.* (1998), and Takayama *et al.* (1988). Figure 9 shows the calcareous nannofossil biostratigraphy of the upper Pliocene to lowermost Pleistocene sequence in the Akita area. The calcareous nannofossil assemblages found in this sequence are characterized by low species diversity and the absence of discoasters. These characteristics are similar to those assemblages found in the arctic region (Sato and Kameo, 1996). The nanoflora in this sequence change abruptly from a *Reticulofenestra* spp. – *Dictyococites* spp. assemblage to a *Coccolithus pelagicus* assemblage at the boundary between the Sasaoka and Tentokuji Formations. Therefore, the boundary can be correlated to Datum A, 2.75 Ma in the late Pliocene. The Pliocene/

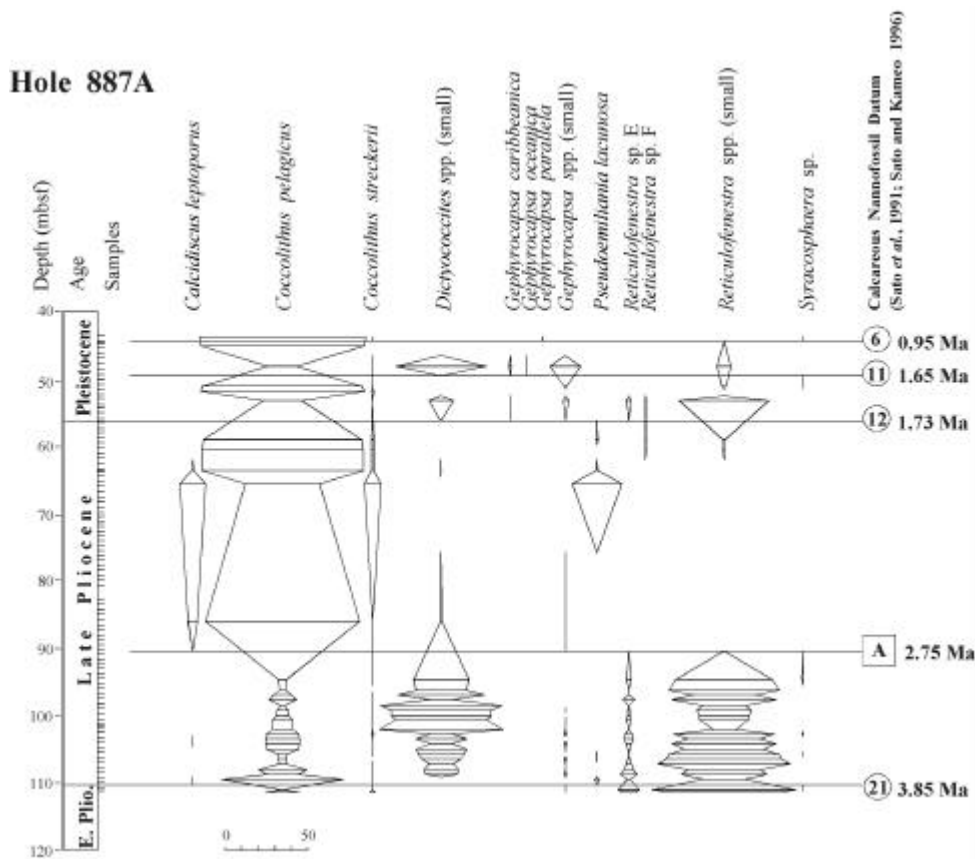


Figure 7. Stratigraphic distribution of calcareous nannofossil species in Hole 887A located near Alaska.

Pleistocene boundary is situated in the uppermost Sasaoka Formation based on first occurrences of *Gephyrocapsa caribbeanica* and *G. oceanica*.

## DISCUSSION

### Late Pliocene paleobiogeography of calcareous nannofossils

The Calcareous nannofossils which occur in the Pliocene sequence in the Pacific Ocean can be divided into three assemblages as follows;

1) Discoaster assemblage: abundant discoasters. It is easy to recognize Pliocene datum planes based on the lineage of Discoaster species.

2) Reticulofenestra – Dictyococcites assemblage: abundant Reticulofenestra and with rare or no discoasters.

3) *Coccolithus pelagicus* assemblage: abundant *Coccolithus pelagicus*, a typical cold water nannofossil. The assemblage is also characterized by low species diversity and the absence of discoasters.

The assemblages from low to middle latitude regions, such as DSDP Holes 292 and 577, ODP Holes

806 and 847, and the Iwaki–Oki well, are characterized by abundant discoasters, and include Discoaster assemblages throughout the late Pliocene. Nannofossils from the upper Pliocene sediments (between 3.85 Ma and 2.75 Ma) in Hole 433A are also characterized by the Discoaster assemblage. However, the sediments deposited between 2.75 Ma and 1.97 Ma are missing at this site. Conversely, calcareous nannofossil assemblages found from ODP Holes 881B and D, 882A, 883C, and 887A, located in high latitude regions of the Pacific Ocean, contain large numbers of Reticulofenestra and Dictyococcites in the lower part of the sequence and change abruptly to the *Coccolithus pelagicus* assemblage at 2.75 Ma (Datum plane A). Pliocene assemblages from the Japan Sea side are very similar to those from in high latitude regions of the Pacific Ocean. Upper Pliocene nannofossils are characterized by the Reticulofenestra – Dictyococcites assemblage (between 3.85 Ma and 2.75 Ma) and the *Coccolithus pelagicus* assemblage (from 2.75 Ma to 1.97 Ma). The Miyakojima section, located in the southern part of Japan, is characterized by the occurrence of discoasters in the lower part of the section, and by low species diversity with abundant *Coccolithus pelagicus* specimens in the upper part.

The late Pliocene calcareous nannofossil paleo-



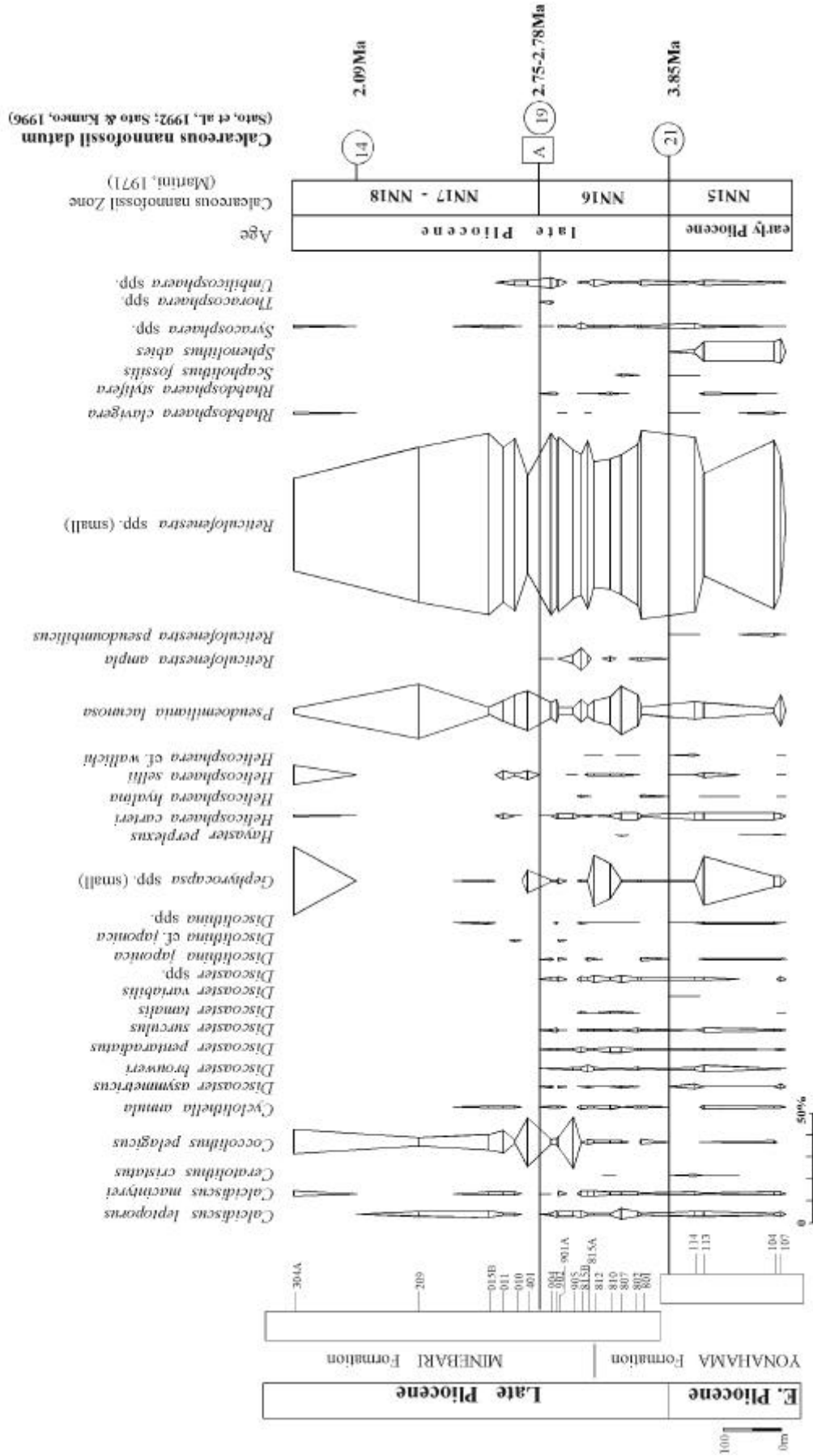


Figure 8. Calcareous nannofossil biostratigraphy of the upper Pliocene sequence of the Miyakojima Section, southern part of Japan.

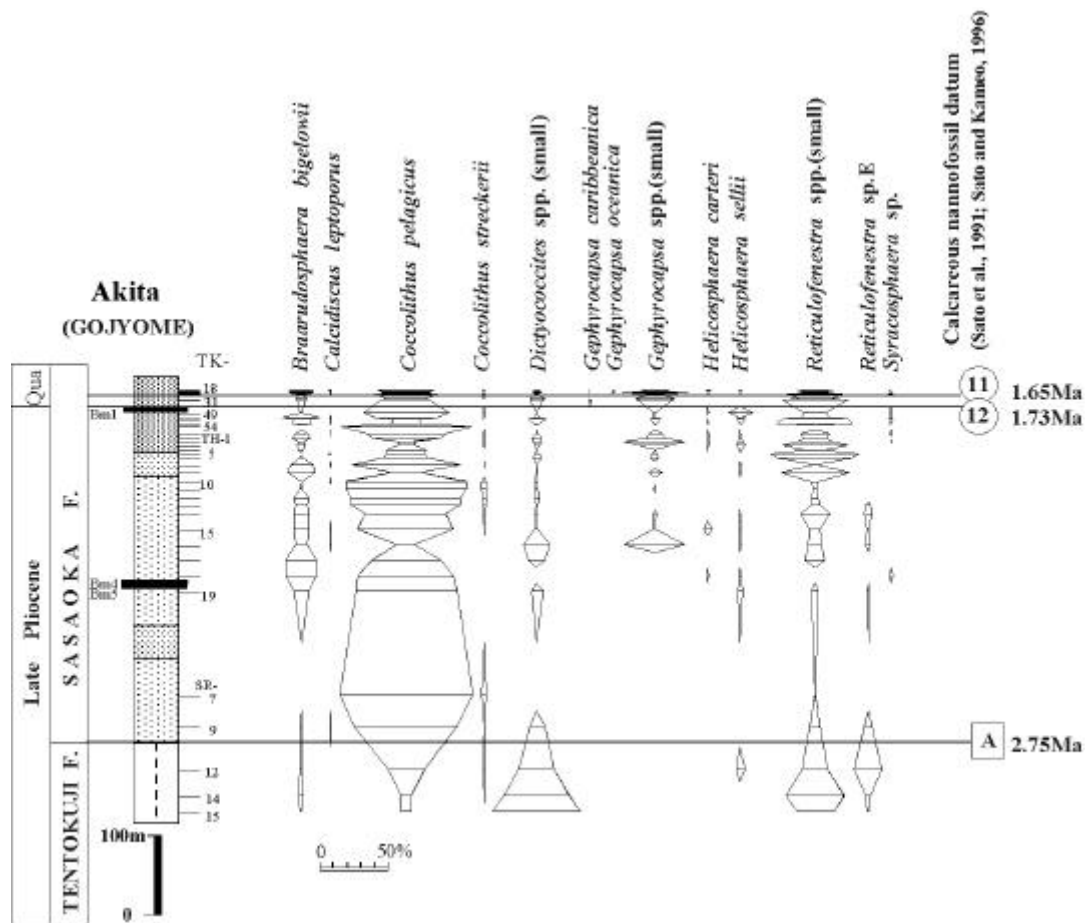


Figure 9. Calcareous nannofossil biostratigraphy of the upper Pliocene sequence of the Gojyome section in Akita area, northern part of Japan.

geography is shown in Figure 10. Between 3.85 Ma and 2.75 Ma, higher latitude regions ( $>45^{\circ}\text{N}$ ) and the Japan Sea side are characterized by the *Reticulofenestra* – *Dictyococcites* assemblage. Equatorial to middle latitude regions are characterized by the *Discoaster* assemblage throughout the late Pliocene (3.85 Ma to 1.97 Ma). Assemblages from high latitude regions and the Japan sea side changed abruptly from the *Reticulofenestra* – *Dictyococcites* assemblage to the *Coccolithus pelagicus* assemblage at 2.75 Ma. Furthermore, the northern boundary of the *Discoaster* assemblage moved southward in the East China Sea of the western Pacific Ocean at 2.75 Ma.

Figure 11 illustrates the change in the paleobiogeography of calcareous nannofossils around Japan. In the early late Pliocene (3.85–2.75 Ma), the northern limit of the *Discoaster* assemblage was situated in  $43^{\circ}\text{N}$  at the Pacific side of Japan, and at  $33^{\circ}\text{N}$  between the Japan Sea and the East China Sea. However, the boundary moved southward along Ryukyu Island in the southern part of Japan, and the East China Sea had a *Coccolithus pelagicus* assemblage between 2.75 Ma and 1.97 Ma.

#### Paleoceanography of the Pacific Ocean around 2.75 Ma: its relation to heavy glaciation of the arctic ocean and to the closure of the Central American seaway

The paleoceanographic events which occurred around 2.75 Ma and discussed previously are closely related in time to the appearance of the Isthmus of Panama (Saito, 1976; Keller *et al.*, 1989; Coates *et al.*, 1992; Duque-Caro, 1990). Although the number of *Coccolithus pelagicus* was rare in total assemblages, Bukry (1991) found the *Coccolithus pelagicus* event at 2.75 Ma in the upper Pliocene sequence of Hole 806B, Ontong–Java Plateau, and correlation to Milankovitch cycles. This characteristic change of *Coccolithus pelagicus* number was also detected by Sato *et al.* (1998). They discussed the timing of the final closure of the Central American seaway based on the geographical distribution of the cold water nannofossil *Coccolithus pelagicus* in the Atlantic and Pacific Oceans. Recently, Kameo and Sato (2000) also discussed the timing of the final elevation of the Isthmus of Panama based on the calcareous nannofossil paleobiogeography around

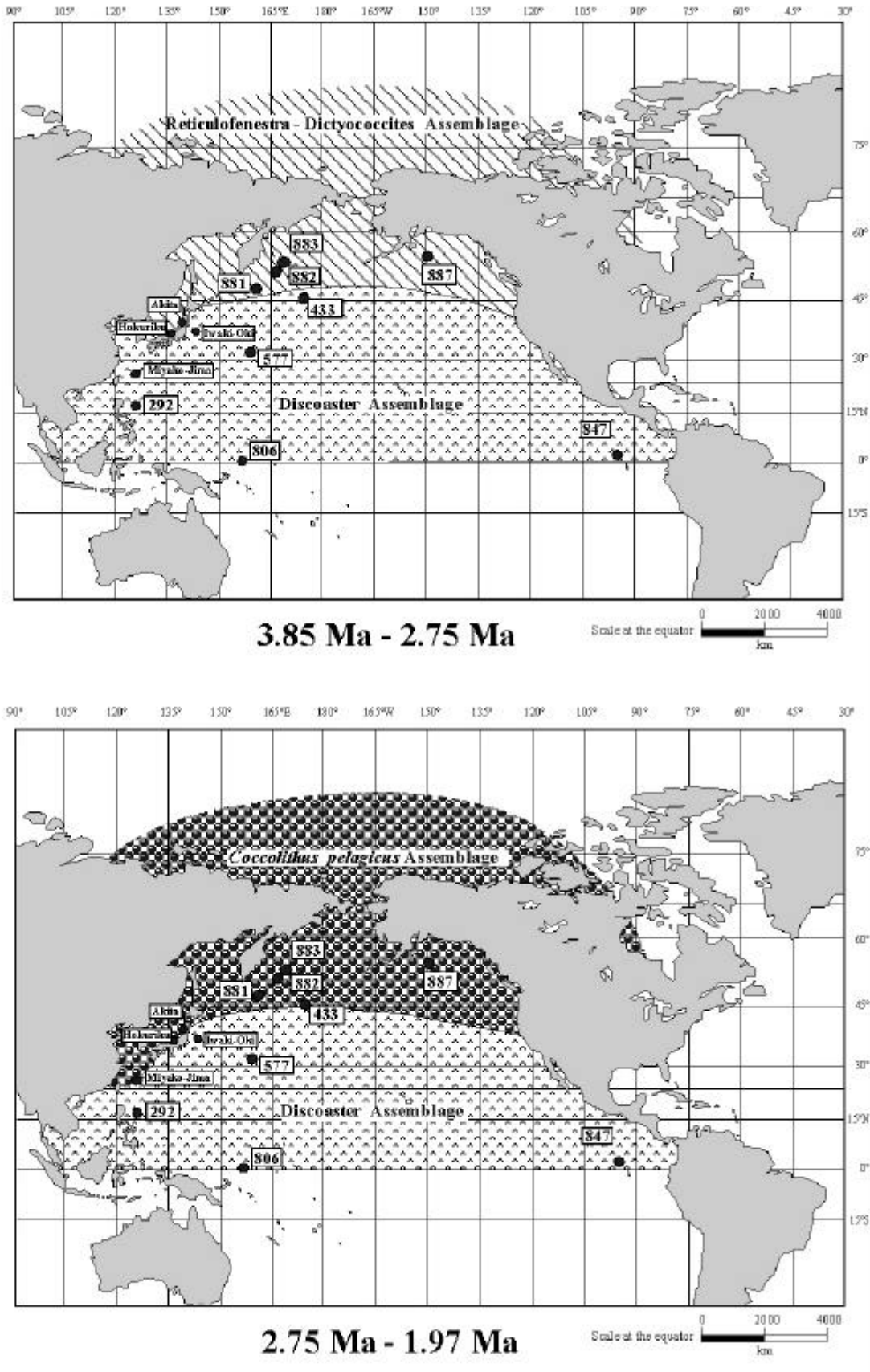


Figure 10. Calcareous nanofossil paleobiogeography in the Pacific Ocean. A: 3.85–2.75Ma, B: 2.75–1.97Ma.

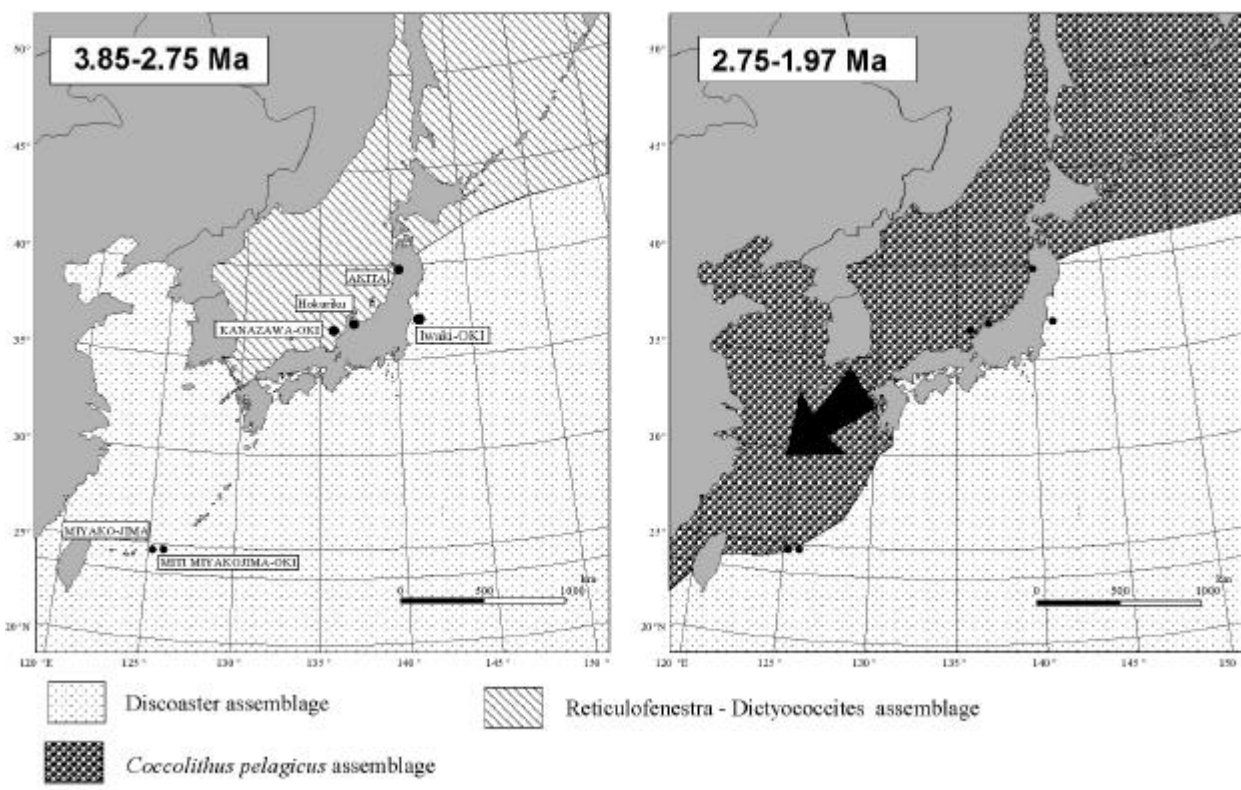


Figure 11. Calcareous nannofossil paleobiogeography around Japanese Islands. A: 3.85 – 2.75 Ma, B: 2.75 – 1.97 Ma. The arrow indicates southward movement of *Discoaster* assemblage boundary.

Central America. They concluded that the final closure of the Isthmus of Panama occurred at 2.75 Ma based on the disappearance in similarities of the calcareous nannofossil assemblages between the Caribbean and the eastern equatorial Pacific regions. The drastic change in calcareous nannofossil assemblages in high latitude regions of the Pacific Ocean at 2.75 Ma, is correlated to the closure of the Central American seaway.

Figure 12 shows the correlation among twelve holes located in the Indian, Pacific, and Atlantic (and Caribbean Sea) Oceans based on the results of this study and Sato *et al.* (1998). The vertical axis indicates the age as controlled by nannofossil datums, and horizontal axis shows the number of *Coccolithus pelagicus* counted in 500 specimens. The abundance of *C. pelagicus* is relatively high in high latitude regions as mentioned previously. Between 3.66 Ma and 2.75 Ma in the late Pliocene, *C. pelagicus* is absent or nearly absent from Holes 806B and 847B, and is rare in Hole 883C, all located in the Pacific Ocean. However, at all holes the abundance suddenly increases after 2.75 Ma. In contrast, *C. pelagicus* is common between 3.66 Ma and 1.65 Ma in the late Pliocene in Holes 999A, 606, 608, 609, and 611 in the Caribbean Sea and Atlantic Ocean. The abundance decreases at about 2.75 Ma at all holes. In particular, the change in the number of *C. pelagicus* in Holes

609 and 611, located in the northeastern Atlantic, is distinct. The distribution patterns of *Coccolithus pelagicus* recognized in the Atlantic Ocean contrast sharply with those seen in the Pacific Ocean. The differences represent the occurrences of different cold current systems during the late Pliocene. In the late Pliocene, between 3.66 Ma and 2.78 Ma, based on the absence of *C. pelagicus* the eastern and western equatorial Pacific were warmer than either the Caribbean Sea or the Atlantic Ocean. This was prior to the final elevation of the Isthmus of Panama (*e.g.*, Coates, *et al.*, 1992; Keller *et al.*, 1989) and warm currents flowed from the Atlantic to the Caribbean and on to the Pacific. The Pacific region was comparatively warmer than the Atlantic as shown by the occurrence of *C. pelagicus* in the Atlantic and the Caribbean Sea (Figure 12). *Coccolithus pelagicus* increased suddenly in the equatorial Pacific at 2.75 Ma and was more abundant than in the Caribbean Sea between 2.75 Ma and 1.65 Ma. In contrast, the abundance of *Coccolithus pelagicus* in the northeast Atlantic decreased at approximately 2.75 Ma. The distribution patterns of *C. pelagicus* in these regions is interpreted as evidence of a new current system which was created by the appearance of the Isthmus of Panama at 2.75 Ma. Warm current communication between the equatorial Atlantic and the equatorial Pacific was cut off due to the

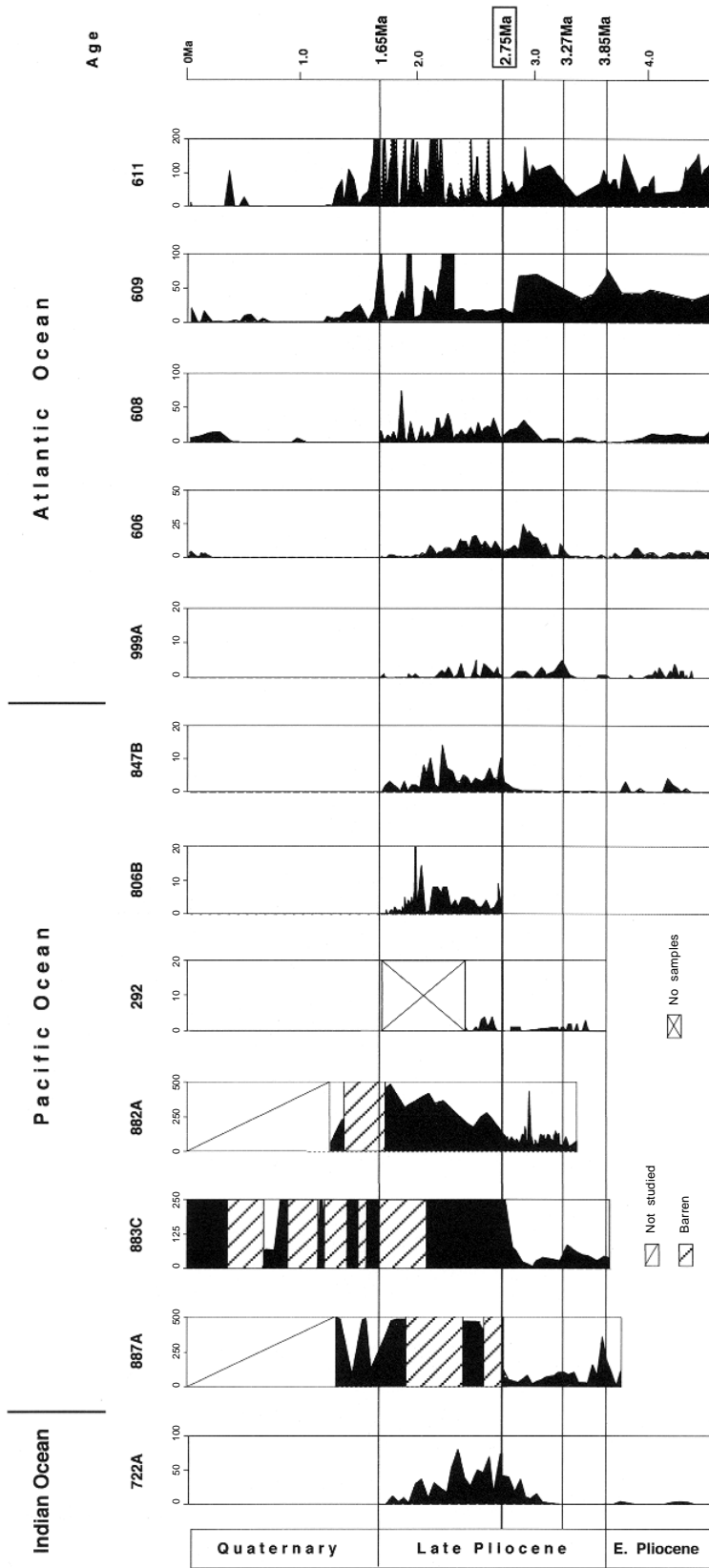


Figure 12. Number of *Coccolithus pelagicus* specimens in total 500 nannofossils during the Pliocene - Pleistocene in Holes 722A, 887A, 883C, 882A, 292, 806B, 847B, 999A, 606, 608, 609, and 611. Vertical axis indicates the age as controlled by nannofossil datums, and horizontal axis shows the number of *C. Pelagicus* specimens.

closure of the Central American seaway. Cold currents from offshore California originated in the North Pacific and flowed into the eastern equatorial Pacific. The warm current in the equatorial Atlantic turned toward the northeast and penetrated northward along the coast of England. This is evidenced by the decrease in the number of *C. pelagicus* in Holes 609 and 611. Therefore, the contrast in the distribution patterns of the cold water species *Coccolithus pelagicus* between the Atlantic and Pacific Oceans is related to the appearance of the Isthmus of Panama at 2.75 Ma. On the other hand, Sato and Kameo (1996) studied the Pliocene to Quaternary calcareous nannofossil assemblages of the Arctic Ocean, and defined Datum plane A based on the floral change from a Reticulofenestra assemblage to a *Coccolithus pelagicus* one. They also discussed that Datum plane A was correlated to heavy glaciation in the high northern latitudes and Arctic Ocean as evidenced by the increasing number of dropstones in these regions. A sedimentological study of the Pliocene sequence of ODP Holes 881 to 887, located in high latitudes of the Pacific Ocean, also shows strong evidence for a major increase in the effects of glaciation at 2.6 Ma (Krissek, 1995). Although the assemblages in the equatorial to low latitude regions consist of the Discoaster type throughout the Pliocene, the assemblages from high latitude regions change from the Reticulofenestra – Dictyococcites assemblage to the *Coccolithus pelagicus* one at 2.75 Ma (Datum plane A) based on the results of our study. The ecology of calcareous nannoplankton has been investigated by many authors (e.g. McIntyre and Be, 1967; Honjo and Okada, 1974; Okada and McIntyre, 1977; Roth, 1994; Samtleben et al., 1995). Roth (1994) described the ecology of Recent nannoplankton, and showed that *C. pelagicus* lives only in high latitude regions such as the northwestern Pacific and the Greenland – Norwegian Sea. On the basis of these ecological data, the drastic increase of this species in high latitude regions of the Pacific Ocean, indicate a change from a temperate to a colder environment at 2.75 Ma (Datum plane A).

From these facts, it is concluded that the change in the calcareous nannofossil paleobiogeography at high latitude region indicates heavy glaciation in high latitude regions, and can also be correlated to final closure of the Central American seaway at 2.75 Ma. These calcareous nannofossil assemblage changes in the high latitude regions at 2.75 Ma contrast sharply with those in the equatorial to low latitude regions where no distinct floral changes occurred throughout the late Pliocene.

## CONCLUSION

We analyzed the calcareous nannofossil assemblages in the late Pliocene to Quaternary sequences of the Pacific Ocean in order to reconstruct the nannofossil paleobiogeography. The results indicate that

assemblages in the equatorial to middle latitude regions are of the Discoaster type throughout the late Pliocene age (3.85–1.97 Ma). However, nannofossil assemblages from high latitude regions and the Japan sea side changed abruptly from the Reticulofenestra–Dictyococcites assemblage (3.85–2.75 Ma) to the *Coccolithus pelagicus* assemblage (2.75–1.97 Ma) at 2.75 Ma. The northern boundary of the Discoaster assemblage moved southward in the East China Sea of the western Pacific Ocean at 2.75 Ma. Changes in the calcareous nannofossil paleobiogeography indicate the strong influence of heavy glaciation in high latitude regions, and can also be correlated to final closure of the Central American seaway at 2.75 Ma.

## ACKNOWLEDGEMENTS

Samples for this study were provided by the Ocean Drilling Program. Deep appreciation is expressed to Dr. Stacia Spaulding for review of the manuscript.

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Manuscript received: June 15, 2000

Corrected manuscript received: November 9, 2000

Manuscript accepted: January 23, 2001