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Calcareous nannofossil biostratigraphy and paleoceanography of late Cretaceous Indian Ocean

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The University of Nebraska - Lincoln, 1994

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CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY

AND PALEOCEANOGRAPHY OF

LATE CRETACEOUS INDIAN OCEAN

by

Im Chul Shin

A DISSERTATION

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Late Cretaceous Indian Ocean

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Im Chul Shin

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GRADUATE COLLEGE
UNIVERSITY OF NEBRASKA

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Adviser: David K. Watkins

Calcareous nannofossil biostratigraphy and the paleoclimatic/paleoceanographic histories of the late Cretaceous (Maastrichtian-late Campanian) from Ninetyeast Ridge (Sites 217 and 758A) and Mozambique Ridge (Site 249) in Indian Ocean were investigated based on the quantitative studies of calcareous nannofossils and down-core distribution patterns of several environmental variables. The cosmopolitan zonation scheme of Perch-Nielsen (1985) was used in sediment age-dating. Marker species occur continuously and relatively abundantly at three sites. Five zones (CC22 to CC26) were identified at Sites 217 and 758A. Site 249 contains five zones (CC19 to CC23). Diagenetic alteration and bottom current effects are minor or negligible in most of samples from these sites.

Site 249 was characterized by relatively minor dissolution, low productivity, and unstable surface water conditions in Zones CC19 and CC20. Zones CC21 and CC22 (late Campanian) was characterized by stable surface water conditions. Bottom water became less corrosive from Zone CC19 to CC22 (early to late Campanian). The late Campanian at Sites 217 and 758A is characterized by lower species diversity and less stable surface water conditions than the Maastrichtian. The Maastrichtian at both sites shows greater species diversity and stable open oceanic conditions. At Site 217, the bottom water

becomes less corrosive from Subzone CC22c to Subzone CC23a. At Site 758A, no changes of bottom water occur from Subzone CC22b to the 360 mbsf (upper part of CC23 and CC22c+CC22b). The corrosiveness of bottom water increases from Subzone CC23b to the top of Maastrichtian at both sites.

Greater species diversity occurs during warm climatic conditions. The surface water temperature becomes warm from Zone CC19 to the middle of Zone CC22. Then, surface water temperatures cooled from the middle of Zone CC22 to Zone CC23 at Site 249. At Sites 217 and 758A, the early late Campanian was characterized by cool surface water temperatures compared to late late Campanian and Maastrichtian. The surface water temperatures cooled from Subzone CC23b through the Maastrichtian at three sites. This early Maastrichtian cooling event occurred globally by the comparison with several previous workers. Cooling started at (or near) the last appearance datum (LAD) of *Aspidolithus parcus constrictus.*

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INTRODUCTION

More than 20 Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) sites have been drilled in the Indian Ocean since the early 1970s. However, the late Cretaceous paleoceanographic history of the area is poorly known. Two DSDP sites (217 and 249) and one ODP site (758) are chosen for this study owing to the well-preserved nature of the upper Cretaceous (Maastrichtian and Campanian) sediments and their tropical or temperate paleolocations.

Two areas are investigated: Ninetyeast Ridge and the Mozambique Ridge. Ninetyeast Ridge and Mozambique Ridge have been above the Carbonate Compensation Depth (CCD) for most of its history (Shipboard Scientific Party, 1974). Therefore, Sites 217, 249, and 758A are ideal sites for the study of biostratigraphy and paleoceanography during the late Cretaceous since the degree of preservation in calcareous fossils has been mainly affected by the CCD depth during the past.

The Ninetyeast Ridge is composed of uplifted oceanic crust (Shipboard Scientific Party, 1974) and formed when the Indian plate moved northward over the Kerguelen hot spot (Luyendyk, 1977; Luyendyk and Rennick, 1977). The Ninetyeast Ridge is approximately 5000 km long and 200 km wide, with an estimated age ranging from 90 Ma at its northern end to 38 Ma to its southern end (Shipboard Scientific Party, 1989). The origin of Ninetyeast Ridge is closely related to the rapid northward motion of the Indian Plate during the period from 90 to 53 Ma (Luyendyk, 1977). The Mozambique Ridge is of continental origin (Shipboard Scientific Party, 1974).

Site 217 (lat. 8°55.57′N, long. 90°32.33′E) is located in 3,010 m water depth on the eastern flank of the northernmost part of Ninetyeast Ridge in the Indian Ocean (Shipboard Scientific Party, 1974; Figure 1). Site 217 contains one of the most continuous and well-preserved upper Cretaceous (Maastrichtian and Campanian) sedimentary records in the

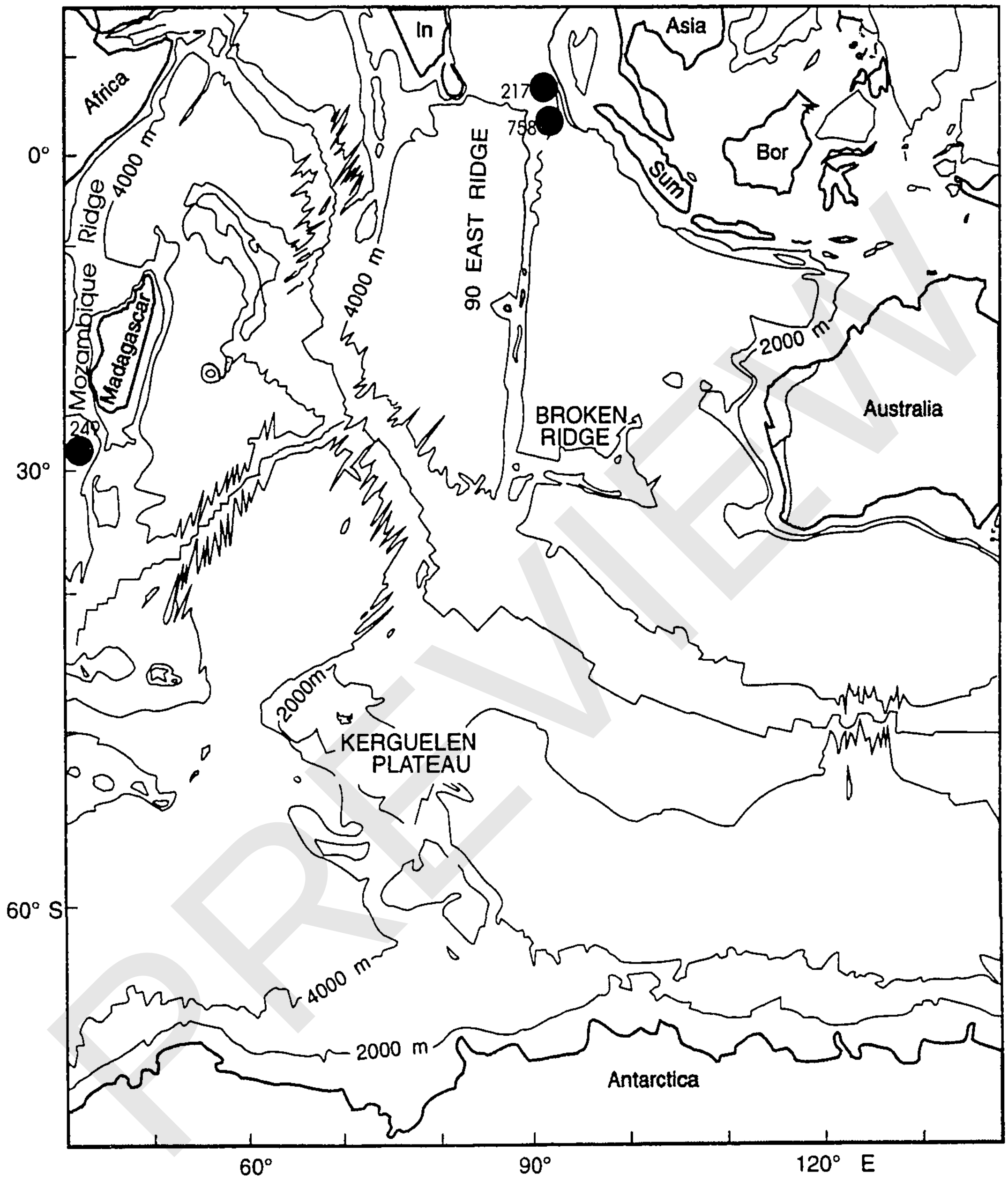

Fig.1. Location map of study area in the Indian Ocean

Indian Ocean. Campanian to Maastrichtian clay-rich nannofossil chalk was recovered from Site 217 (Shipboard Scientific Party, 1974).

Site 758A was drilled at the northern end of Ninetyeast Ridge. Three holes were drilled at Site 758; 758A, 758B, and 758C. Hole 758A, which penetrated the Cretaceous, is at 5° 23.049' N, 90° 21.673' E, and has a water depth of 2,923.6 m (Fig. 1). Campanian to Maastrichtian tuffs and calcareous chalks were recovered at Site 758A (Shipboard Scientific Party, 1974).

Site 249 (lat. 29° 56.99' S, long. 36° 04.62' E) is located in the extreme western Indian Ocean, on the Mozambique Ridge, and has a water depth of 2088 meters (Fig. 1). The upper Cretaceous sediments (Maastrichtian and Campanian) were deposited under tectonically quiescent conditions (Shipboard Scientific Party, 1974; Vallier, 1974). Sigal (1974) concluded that Site 249 had reached open marine conditions by the late Cretaceous and the Maastrichtian/Campanian sediments show an offshore facies. Cores 17 to 23 (upper Cretaceous) are composed of brown and gray foram-bearing clay-rich nanno chalk.

Site 249 is characterized by a sedimentary sequence with highly variable sedimentation rates and sedimentation hiatuses (Gieskes, 1974). Two major disconformities during the Cretaceous and the Miocene are recognized by Schlich et al. (1974). One hiatus lies between the early Cenomanian (~97 m.y.) and the late Campanian (71-73 m.y.), and the other is between the late Maastrichtian (~65-68 m.y.) and the middle Miocene (14-14.5 m.y.). Continuous coring and good core recovery (79 %) (Shipboard Scientific Party, 1974) allowed me to develop good biostratigraphic and paleoceanographic histories of Site 249.

The circulation of surface and deep waters are controlled by climate which influences the total thermal structure of the hydrosphere, the distribution of ecosystems, the distribution of sediments, and the chemistry of the ocean water. Calcareous nannofossils are sensitive to paleoenvironmental changes. The study of calcareous nannofossils

(phytoplankton) plays an important role in understanding how ocean surface waters respond to paleoclimatic/paleoceanographic changes through time.

Calcium carbonate dissolution also affects the nannofossil assemblages and the size distribution patterns of microfossils and sediments (Berger, 1967). Therefore, the evaluation of calcium carbonate dissolution is important for paleoceanographic interpretation. Calcium carbonate dissolution is a surface reaction controlled (Berner, 1978). There is a direct relationship between the calcium carbonate dissolution and climatic changes (Berger, 1973; Luz, 1973: Ramsay, 1974; Thompson and Saito, 1974; Gardner, 1975; Williams et al., 1985). Several workers explain calcium carbonate dissolution in terms of the production of bottom water and/or water circulation (Gardner, 1975; Berner, 1978; Balsam, 1982). Berger (1970) also suggested that the calcium carbonate dissolution is related to the watermass distribution.

The following variables were used for the study of calcium carbonate dissolution histories: nannofossil species abundance variations, percentage of broken planktonic foraminifera, percentage of calcium carbonate, coarse fraction content, and planktonic/benthic foraminiferal ratio.

There are several studies of dissolution related to Cenozoic and Cretaceous calcareous nannofossils (Matter et al., 1974; Thierstein, 1980, 1981; Roth and Krumbach, 1986; Erba, 1992). Calcareous nannoplankton live near the surface of the ocean and are eaten by planktonic zooplankton. Their skeletons are excreted and settle down to the bottom of the ocean as fecal pellets, which may eventually result in their complete dissolution because of calcium carbonate undersaturation of the ocean water. Therefore, interpretating dissolution effects can provide information about the physicochemical conditions on the sea floor (and thus, bottom water conditions) during the past.

Hypotheses and Purpose

The purpose of this paper is to investigate how calcareous nannoplankton responded to paleoclimatic/paleoceanographic changes during the late Cretaceous in the Indian Ocean. Three hypotheses are suggested for testing in this study. The first hypothesis is to test the applicability of the ice-age Cenozoic several environmental variables (mainly, species diversity indices) to the ice-free Cretaceous period. Several previous workers showed that greater species diversity (mainly richness) occurs during warm climatic period during the Cenozoic. However, there is no documentation about the relationship between species diversity indices and surface water temperatures during Cretaceous period.

The second hypothesis is to test the true meaning of dissolution index (D.I.) values of upper Cretaceous calcareous nannofossils. Several previous workers used D.I. values for the dissolution of calcium carbonate during Holocene and middle Cretaceous.

The third hypothesis is to test whether the early Maastrichtian cooling event is a local or global phenomenon. Evidence from other studies suggests an early Maastrichtian climatic cooling event in the Southern Ocean (Huber and Watkins, 1992; Watkins et al., in press). If this cooling is global, then the effects should be evident even at low latitudes. To test this hypothesis, samples from three temperate or tropical paleolocations were chosen.

To accomplish this purpose and to test these hypotheses, firstly, biostratigraphic studies of calcareous nannofossils were done on the upper Cretaceous sediment to determine an accurate time framework. Secondly, the species diversity distribution patterns and dissolution index (D.I.) values of calcareous nannofossils, broken planktonic foraminifera, and planktonic/benthic foraminifera ratios (P/B) were plotted according to the above determined time framework to investigate the characteristics of surface and bottom water masses conditions and to examine the carbonate dissolution history. Thirdly, calcareous nannofossils were quantitatively counted to study the temporal distribution

patterns of species diversity, equitability, abundance variations, and some climatic indicator species. Finally, sedimentological analysis (calcium carbonate and coarse fraction) was performed to investigate the nature of water masses, degrees of carbonate dissolution, and nature of bottom current activities.

MATERIALS AND METHODS

Ninety-seven upper Cretaceous (Maastrichtian and Campanian) samples from core 17 to core 36 of Site 217 were selected with approximately 1 meter sampling intervals for this study. Seventy six upper Cretaceous samples from core 32X to core 57R of Site 758A were selected with approximately 1 m sampling intervals. Fifty-three upper Cretaceous samples from cores 17 to 23 at Site 249 were selected with approximately 1 meter sampling intervals.

Before making smear slides, exposed sediments on the surface of each sample were carefully scraped off to eliminate any contamination. Five hundred specimens of calcareous nannofossils in each smear slide of untreated sediments were counted and identified under the light microscope. The percentages of calcareous nannofossil species were calculated to observe any changes with down-core depth. After identification of 500 specimens, an additional search was conducted to find any species missed by the counting procedure. Species which do not occur within 500 countings are designated with a "R" in species percentage chart. Biostratigraphic assignments are based on the divisions of Perch-Nielsen (1985). Chronostratigraphic correlation is based on Erba, et al. (in press).

Dissolution index (D.I.) of calcareous nannofossils was calculated based on dissolution rankings (Thierstein, 1980) of individual species and percentage data. Different calcareous nannofossil taxa dissolve at different rates, with some species being solution susceptible and others solution resistant. Calculation of the dissolution index utilizes equations proposed by Roth and Berger (1975). The dissolution index is calculated as follows: $D.I.=\Sigma (P_iR_i)/\Sigma (P_i)$, where P_i is the proportion of species i, and R_i is the rank of species i. The dissolution rank of species was determined by the experimental evidence of Thierstein (1980).

At Site 217, fifteen species which constitute greater than 5 % in any one sample were used for the dissolution index calculations. These 15 species and their rankings are shown

in Table 1. A lower rank number indicates dissolution-resistant species. At Site 758A, the D.I. values are not calculated due to the absence of a published rank for *R. parvidentatum* which is one of the most abundant species in the samples. At Site 249, fifteen species which constitute greater than 5 % in any one of the sample were used for the dissolution index (D.I.) calculations. These fifteen species and their rankings are shown in Table 2.

Planktonic foraminifera fragmentation is a good index for the intensity of calcium carbonate dissolution (Thunell, 1976; Balsam, 1982) and a very sensitive index for the early stages of dissolution (Vincent and Berger, 1981). The percentage of broken specimens primarily reflects the effect of calcium carbonate dissolution due to weakening of the tests (Phleger et al., 1953; Berger, 1970) and secondarily reflects mechanical factors (Phleger et al., 1953). Berger (1970) pointed out that increased fragmentation of fossil assemblages has been directly related to increased dissolution. The planktonic foraminifera fragmentation is not sensitive to terrigenous sediment influx (Balsam, 1982). In this study, fragmentation of planktonic foraminifera was used as a proxy measure for dissolution. In the cores, grain sizes of greater than 150 µm were used for countings of broken planktonic foraminifers to avoid any duplicate counting of fragments.

Planktonic/benthic foraminifera ratio can be used for paleobathymetric interpretation (Parker and Berger, 1971). The P/B ratio increases from shallow water to deeper water. Planktonic/benthic foraminifera ratio also is a function of preservation and is strongly affected by selective solution of foraminiferal tests during sedimentation (Berger, 1968, 1973). In this study, P/B ratio was used as a proxy measure for carbonate dissolution. The ratio of planktonic to benthic foraminifera (P/B) was counted from the size fraction greater than 63 µm to avoid any information loss. Planktonic/benthic foraminifera ratios were calculated as follows: (P/P+B)X100, where P=number of planktonic foraminifera and B=number of benthic foraminifera.