PLEISTOCENE CALCAREOUS NANNOFOSSIL PALEONTOLOGY: INSIGHTS FROM INTEGRATED OCEAN DRILLING PROGRAM EXPEDITION 346 IN THE JAPAN SEA

by

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PLEISTOCENE CALCAREOUS NANNOFOSSIL PALEONTOLOGY: INSIGHTS FROM INTEGRATED OCEAN DRILLING PROGRAM EXPEDITION 346 IN THE JAPAN SEA

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This study presents the first attempts to synthesize calcareous nannofossil biostratigraphy of the Japan Sea, to evaluate the nature of the Tsushima Warm Current at high resolution using calcareous nannofossils, and to assess effects of oceanographic restriction in the Japan Sea on the distribution of calcareous nannofossils during the Pleistocene. Integrated Ocean Drilling Program Expedition 346 and International Ocean Discovery Program Expedition 350 provide a combination of lithostratigraphic, paleomagnetic, and paleontological data that are incorporated herein with high resolution calcareous nannofossil analyses, allowing for an unprecedented assessment of nannofossil assemblage dynamics in the Japan and Philippine seas during the Pleistocene.

Integration of these data sets is of particular importance in interpreting paleoenvironmental history of the Japan Sea where regional environmental conditions played a large role in the distribution of calcareous nannofossil bioevents in the Pleistocene due to sensitivity to glacial-interglacial cyclicity resulting from shallow sill depths. The last occurrences (LO) of *Helicosphaera sellii* and *Reticulofenestra asanoi* occur later in the Japan Sea than in open ocean sites with the LO of *H. sellii* in Marine Isotope Stage (MIS) 21 and the LO of *R. asanoi* in MIS 37. This corresponds more closely to distribution patterns observed in the high latitude North Atlantic Ocean than in the adjacent Pacific Ocean. Calcareous nannofossil assemblage data were collected from Site U1427 in order to study evolution of the Tsushima Warm Current, which played a significant role in the paleoceanographic and paleoecological evolution of the Japan Sea.

Nannofossil abundance data allow for the identification of three discrete intervals at Site U1427: I) MIS 31-27, II) MIS 27-21, and III) MIS 21-17. High-resolution quantitative analyses of samples recovered from Site U1437 allow for the determination of differences in the nannofossil assemblages between the marginal Japan Sea and the adjacent, open ocean Philippine Sea. Nannofossil assemblage data indicate warmer and more oligotrophic surface waters in the Philippine Sea throughout the middle Pleistocene. Additionally, the last occurrence of *Reticulofenestra asanoi* occurs stratigraphically higher at Site U1426 in the Japan Sea than in the Philippine Sea.

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Chapter 1: Introduction

1.1. Overview

This dissertation presents the results of Pleistocene calcareous nannofossil paleontology from Integrated Ocean Drilling Program Expedition 346 in the Japan Sea and International Ocean Discovery Program Expedition 350 in the Philippine Sea. These localities are ideal to examine the effects of paleoceanography on calcareous nannoplankton assemblages due to their distinct oceanographic settings. In addition, Site U1427 in the Japan Sea, which is studied in detail in this dissertation, provides a unique opportunity to conduct high-resolution paleoceanographic research in the Japan Sea due to its good carbonate preservation, high sediment accumulation rates, and high core recovery during drilling (Expedition 346 Scientists, 2014). The goal of this work is to conduct a comprehensive analysis of calcareous nannoplankton biostratigraphy and paleoecology in a highly dynamic marginal sea, the Japan Sea, and an adjacent, but latitudinally similar, open ocean setting in the Philippine Sea. The results presented here will aid in our understanding of how nannoplankton assemblages are affected by oceanographic variations across glacial-interglacial cycles of the Pleistocene. They will also assess how differing paleoceanographic conditions affected the stratigraphic distribution of nannofossil bioevents.

1.2. Past Research

Integrated Ocean Drilling Program Expedition 346 in the Japan Sea recovered an unparalleled archive of atmosphere-ocean linkages in the 6135 m of core recovered from July through September, 2013. High core recovery allowed for the analyses of nannofossil assemblages in a variety of latitudes, oceanographic settings, and water depths in the Japan Sea (Expedition 346 Scientists, 2014).

Tada (1994) first subdivided the paleoceanographic evolution of the Japan Sea into five stages. His Stage 5 (from 2.5-0 Ma) was further subdivided into three substages by Kitamura et al. (2001). This dissertation includes data from the middle Pleistocene encompassing Substages II (1.71-1.52 Ma) and III (1.52-0 Ma). Substages II and III are characterized by inflow of the Tsushima Warm Current (TWC) during every interglacial highstand, except MIS 25, 23, and 21.3 (Kitamura and Kimoto, 2006), with increasing isolation of the Japan Sea in Substage III via narrowing and/or shallowing of the northern straits.

The evolution of the TWC is reflected in the stratigraphic distribution of marine organisms such as mollusks, diatoms, radiolarians, ostracods, foraminifera, and nannoplankton (see Gallagher et al., 2015 for a synthesis of investigations of the Pliocene to recent TWC); however, little work was published on the paleoecological interpretation of nannofossil assemblages in the seas surrounding Japan. Previous studies identified nannofossil assemblages suggesting the presence of the Kuroshio Current (Chinzei et al., 1987; Su and Wei, 2005). Ocean Drilling Program Site 798 was re-drilled during Expedition 346 as Site U1426. Muza (1992) included three nannofossil species in his TWC index from Site 798: *Gephyrocapsa oceanica, Calcidiscus leptoporus,* and *Helicosphaera carteri,* which he used, in combination with carbonate preservation, to estimate the position of the Subpolar Front. This front is considered to be related to the strength of the TWC in the Japan Sea over the last 1.5 million years (Isoda, 2011). No other studies assessed the TWC in the Pleistocene using calcareous nannofossil assemblages as paleoecological proxies.

International Discovery Program Expedition 350 drilled Site U1437 from March to May, 2014. The primary goal of Expedition 350 was to characterize subduction processes in the Izu-Bonin-Mariana arc by drilling the first holes in the Izu rear arc. While pursuing the primary goal of the expedition, a complete and continuous Pleistocene sedimentary section with well-preserved nannofossils was also recovered at Site U1437, providing a unique opportunity to compare assemblages as this site in the Philippine Sea to those in the nearby, but oceanographically distinct, Japan Sea. This dissertation contains the first and only analysis to date of nannofossil assemblages from this Pleistocene section.

1.3. Motivation

The motivation for this study is twofold. The first goal was to evaluate the effect of oceanographic restriction on the Pleistocene nannofossil assemblage in the Japan Sea in order to determine the impact those oceanographic conditions had on the distribution of nannofossil bioevents. Understanding the influence that varying oceanographic conditions have on biostratigraphy is critical in allowing nannofossil workers to evaluate the reliability of bioevents in locations across the globe. This was achieved by comparing the nannofossil biostratigraphy of the Japan Sea to previously published biostratigraphic studies from across the globe, in addition to comparing the results to the nearby Philippine Sea Site U1437.

The second goal was to use nannofossil assemblages in a high-resolution setting to evaluate the evolution of the Japan Sea and the TWC through the middle Pleistocene. Site U1427 is ideal for this type of study due to its high sediment accumulation rates, high core recovery, good preservation of carbonate due to its shallow depth, and unique position directly under the influence of TWC.

This work was conducted in advance of other data sets (e.g., orbitally-tuned age models) availability. The age model will improve as other data sets become available. The age models used for this dissertation are included in the respective chapters. Data used in the generation of age models are enclosed in the Appendix.

1.4. Dissertation Structure

This dissertation is organized as a series of three manuscripts that will be submitted for publication. The three manuscripts are divided into separate chapters (Chapters 2-4). Approximately half of the shipboard nannofossil data in Chapter 2 was collected by Mariem Saavedra-Pellitero (Expedition 346 nannofossil paleontologist), while the remaining half was collected by myself. All of the nannofossil data from post-cruise samples included in Chapters 2 and 3 were collected by me. Approximately half of the data collected from Expedition 350 and included in Chapter 4 was generated by Zachary Kita (Expedition 350 nannofossil paleontologist), while half was collected by me. Each chapter (i.e., manuscript) is formatted according to the specific journal guidelines. Specifically, the formatting guidelines used are from *Marine Micropaleontology*. Figures and tables are included within the text of each chapter. Chapter 1 (i.e., this chapter) is an introduction to the project, and Chapter 5 presents conclusions and synthesizes the results from the three manuscripts.

Chapter 2

Chapter 2 is entitled "Impact of Oceanographic Isolation of the Japan Sea on Calcareous Nannofossil Distribution during Pleistocene Glacial-Interglacial Cycles: Insights from IODP Exp. 346" by Bobbi Brace, Mariem Saavedra-Pellitero, and David K. Watkins. This paper compiles the first synthesis of nannofossil biostratigraphy in the Japan Sea based on samples collected from Integrated Ocean Drilling Program Expedition 346. It presents the stratigraphic distribution of Pleistocene calcareous nannofossil bioevents in comparison to global datasets from previously published work. The last occurrences of *Helicosphaera sellii* and *Reticulofenestra asanoi* are demonstrated to occur later (MIS 21 and 37, respectively) in the Japan Sea than in open ocean sites. These later LO's correspond more closely to distribution patterns observed in the high latitude North Atlantic Ocean than in the adjacent Pacific Ocean.

Chapter 3

Chapter 3 is entitled "Interpreting the Tsushima Warm Current through the Middle Pleistocene in the Sea of Japan from Calcareous Nannofossil Assemblages" by Bobbi Brace, Mariem Saavedra-Pellitero, and David K. Watkins. This paper presents a high resolution analysis of sediment samples recovered from Site U1427 in the Japan Sea, which is directly overlain by the TWC path. Three distinct intervals in the evolution of the TWC were identified based on nannofossil assemblage data: I) MIS 31-27, II) MIS 27-21, and III) MIS 21-17. Interval I is characterized by recurring inflow of the Tsushima Warm Current during every interglacial, when nannofossil assemblage data suggest relatively stable conditions until the MIS 28/27 boundary. Interval II represents a period in when the TWC flowed only intermittently; with the return of TWC influence in MIS 21 indicated by the sudden increase of warm water and high nutrient indicators. This change in nannofossil assemblage character during MIS 21 has also been observed in the North Atlantic and Southern ocean, which may indicate that these changes are driven by global climatic factors in addition to recording a time of reconnection between the Japan Sea and the Pacific Ocean. Interval III is representative of connectivity between the Pacific Ocean and Japan Sea during every interglacial which was reestablished during MIS 21. The increase of warm and/or oligotrophic taxa and a general increase in diversity suggest more stable and stratified surface waters during Interval III

Chapter 4

Chapter 4 is entitled "Paleoecology and biostratigraphy of middle Pleistocene calcareous nannofossils from the western Pacific: a comparison of open ocean and marginal sea assemblages" by Bobbi Brace, Zachary Kita, Mariem Saavedra-Pellitero, and David K. Watkins. This paper presents the results of a new, high-resolution data set collected from samples taken from Site U1437 in the Philippine Sea and compared to Sites U1426 and U1427 in the adjacent,

but oceanographically distinct, Japan Sea. Nannofossil assemblage data indicate warmer and more oligotrophic conditions in the Philippine Sea than the Japan Sea throughout the middle Pleistocene. Abundance fluctuations in the nannofossil assemblage are generally low amplitude until the interval MIS 19-16 (790 to 620 ka) which may reflect the onset of the Mid Pleistocene Transition (approximately 920 ka); however, the offset in timing and lack of consistent response among taxa suggest that a complex network of factors is responsible for the apparent shift in the Philippine Sea. Additionally, the last occurrence of *Reticulofenestra asanoi* occurs stratigraphically higher at Site U1426 in the Japan Sea than in the Philippine Sea. The depth of this datum within Hole U1426A yields an estimated age of 0.84 Ma (lower MIS 21) - the same stratigraphic level at which it has been observed in the high latitude North Atlantic. Therefore, the extinction of *R. asanoi* in the Japan Sea appears to follow more closely patterns observed in the high latitude North Atlantic (MIS 21) than those observed nearby in the Philippine Sea (MIS 23).

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