

A multi-proxy study of planktonic foraminifera to identify past millennial-scale climate variability in the East Asian Monsoon and the Western Pacific

Warm Pool

by

Stefanie Dannenmann

A Dissertation

Submitted to the University at Albany, State University of New York

in Partial Fulfillment of

the Requirements for the degree of

Doctor of Philosophy

College of Arts & Sciences

Department of Earth and Atmospheric Sciences

2001

ABSTRACT

High resolution paleo-climatological data from IMAGES core MD97-2141 (8.80° N, 121.31° E) located in the Sulu Sea within the western tropical Pacific reveal the first evidence of continuous millennial-scale variability in surface ocean conditions over the last 150,000 years. The millennial-scale planktonic foraminiferal oxygen isotope ($\delta^{18}\text{O}$) oscillations of *Globigerinoides ruber* (*G. ruber*) between 30,000-65,000 years (MIS3) are apparently in-phase with the Greenland ice core record and have amplitudes 1/3 to 2/3 the size of the Sulu Sea glacial-interglacial $\delta^{18}\text{O}$ amplitude of 1.3 ‰. In the same interval variations in planktonic foraminiferal Mg/Ca suggest that millennial-scale sea surface temperature (SST) variations were small (0.6-1°C) and out-of-phase with $\delta^{18}\text{O}$ indicating that $\delta^{18}\text{O}$ variability was mainly driven by changes in surface water salinity. This result implies that the linked East Asian monsoon and the western Pacific Intertropical Convergence Zones, both influencing the Sulu Sea, have fluctuated on the same millennial time scale as higher latitude climatic systems.

To further investigate the origin of the MIS3 $\delta^{18}\text{O}_{G.ruber}$ variations, the relative abundance of all planktonic foraminifer species and the $\delta^{18}\text{O}$ values of four planktonic foraminifer species was determined during MIS3. Combined, these data provide a detailed reconstruction of changes in the western tropical Pacific thermocline structure. The $\delta^{18}\text{O}$ composition of the mixed-layer foraminifera (*G. ruber* and *Globigerinoides sacculifer*) and upper thermocline species (*Neogloboquadrina dutertrei*) displays poor similarity with the $\delta^{18}\text{O}$ of the sub-thermocline dweller *Globorotalia crassaformis*. $\delta^{18}\text{O}_{G.crassaformis}$ shows larger $\delta^{18}\text{O}$ variations (~1 ‰) than the surface dwellers indicating past fluctuations in

the influence of high salinity North Pacific Tropical Waters that currently enter the Sulu Sea across the Mindoro Strait during the months of the winter monsoon. The faunal and isotopic data suggest a switch from winter to summer monsoon predominance after 55 kyr. However this predominance is interrupted by at least three episodes of increased winter monsoon between 42-46 kyr.

Comparison of the proxy SST and planktonic foraminiferal $\delta^{18}\text{O}$ profiles for the last glacial/interglacial sequence from fourteen cores in tropical and subtropical oceanic settings indicates that termination I in $\delta^{18}\text{O}$ coincides with SST change at some sites, while $\delta^{18}\text{O}$ lags SST by 3,000 years at other locations. A comparison of SST and $\delta^{18}\text{O}$ shows a linear increase in SST from glacial to interglacial conditions. Sites where SST is leading the $\delta^{18}\text{O}$ record indicate fresher conditions during the LGM, and these sites are all located in areas influenced by increased atmospheric water vapor during times of today's La Niña.

DEDICATION

To my parents and my brother Tim

ACKNOWLEDGMENTS

It has been an exceptional journey - one that I had never dreamed of. I am deeply indebted to my advisor Dr. B.K. Linsley for his encouragement, advice, mentoring, and research support throughout my doctoral studies. I also truly appreciate his engagement in the final stages of this dissertation. I am fortunate to have had Dr. Delia Oppo, Dr. Andrei Lapenis, and Dr. Yair Rosenthal as my committee members. I have enjoyed every moment to work with such a group of energetic people. This dissertation project also gave me the opportunity to work with great people at Woods Hole Oceanographic Institution and Rutgers University. Particularly, I would like to acknowledge Dr. Dick Norris for opening his world of foraminifera to me. Thanks to all of you for sharing your research ideas and enthusiasm about this project.

Thanks are also extended Dr. Win Means and Dr. Bill Kidd who have been tremendously helpful not only in their academic advisement but also in their personal openness. Steve Howe has been a great friend and extraordinary help in teaching my ways around the stable isotope lab, and editing the first draft of this dissertation. A big hug and special thanks go to Diana Paton for not going into early retirement. I could not have finished without her presence. I appreciate all their friendships and their collective encouragement to finish this dissertation.

I thank the IMAGES Program for allowing access to the great core MD97-2141. Thanks go to the WHOI-NOSAMS AMS facility that generated the AMS-data, and Liz Lukowski and Susan Trimarich for their technical support. This project has been funded by NSF Awards #OCE 9710156 to B.K. Linsley, #OCE

9710097 to D.W. Oppo for AMS analyses and lower 18 m $\delta^{18}\text{O}$ analyses, and #OCE 9987060 to Y. Rosenthal for Mg/Ca analyses.

I would especially like to thank my good friends Markus Landthaler, Chris Nemeth, Nicole Dentzien, Erich Nussbaum, my office-mate Barbara Fletcher and the Friday morning Quintessence breakfast club for helping me grow in various ways and for keeping this Ph.D. fun. I wish to acknowledge all of my other friends who have listened to me complain, cry and laugh through these past years. I could not ask for better friends.

There are not enough words to thank my boyfriend and best friend Stelios Matsopoulos for his love and support. His patience and understanding during this Ph.D. and particularly during difficult times was unselfish and appreciated more than he knows.

Finally, I owe a huge debt of gratitude to my parents' and my brother Tim's love and support, as well as their encouragement not only the course of my research career but throughout my entire life. This dissertation is dedicated to them.

To all of you, thank you

TABLE OF CONTENTS

	Page
ABSTRACT _____	ii
DEDICATION _____	iv
ACKNOWLEDGMENTS _____	v
TABLE OF CONTENTS _____	vii
PREFACE _____	1
CHAPTER 1: Introduction to the Sulu Sea _____	4
1.1 Regional Setting _____	5
1.2 Surface Water Hydrography _____	5
1.3 Deep Water Hydrography _____	10
1.4 The Monsoon and the ENSO cycle _____	11
CHAPTER 2: Millennial-scale climate variability in the tropical western Pacific during 30,000 - 90,000 years B.P. _____	12
2.1 Abstract _____	13
2.2 Introduction _____	14
2.3 Methods _____	15
2.3.1 Oxygen isotope analysis _____	15
2.3.2 Mg/Ca analysis _____	16
2.3.3 Age model _____	17
2.4 Results _____	19
2.5 Discussion _____	25
2.6 Conclusions _____	28

CHAPTER 3: Variability of Marine Isotope Stage 3 upper water-column structure in the Sulu Sea:

Isotopic evidence and Faunal Evidence	29
3.1 Abstract	30
3.2 Introduction	31
3.3 Area Description	33
3.4 Deep Water Hydrography	33
3.5 Depth Ecology of Planktonic Foraminifera	36
3.6 Material and Methods	39
3.6.1 Oxygen Isotope Analysis	39
3.6.2 Faunal Abundance	40
3.6.3 Chronology	40
3.7 Results	41
3.7.1 Oxygen Isotopic Composition of <i>G. ruber</i> and <i>G. sacculifer</i>	41
3.7.2 Oxygen Isotopic Composition of deeper dwelling foraminifera	43
3.7.3 Faunal Abundance	44
3.8 Discussion	48
3.9 Conclusions	54

CHAPTER 4: The relationship between changes in temperature and precipitation in tropical oceans during the Last Glacial Maximum _____ 55

4.1 Abstract _____	56
4.2 Introduction _____	57
4.3 Methods _____	59
4.4 Results _____	64
4.5 Discussion _____	66
4.5.1 Cores where SST synchronous with $\delta^{18}\text{O}$ _____	66
4.5.2 Cores where SST leads $\delta^{18}\text{O}$ _____	69
4.6 Conclusions _____	76
REFERENCES _____	77

APPENDICES

APPENDIX I: IMAGES core MD97-2141: $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data from <i>Globigerinoides ruber</i> _____	90
APPENDIX II: IMAGES core MD97-2141: Mg/Ca and Sr/Ca data from <i>Globigerinoides ruber</i> _____	110
APPENDIX III: IMAGES core MD97-2141: $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data from <i>Globigerinoides sacculifer</i> _____	116
APPENDIX IV: IMAGES core MD97-2141: $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data from <i>Neogloboquadrina dutertrei</i> _____	119
APPENDIX V: IMAGES core MD97-2141: $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data from <i>Globorotalia crassaformis</i> _____	122
APPENDIX VI: IMAGES core MD97-2141: Relative abundance of planktonic foraminifera between 35-60 kyr _____	125

**APPENDIX VII: IMAGES core MD97-2141: Sample weight and occurrence
of pteropods and ash layers _____ 127**

LIST OF TABLES

Table 1: Radiocarbon ages for MD97-2141 _____ 18

Table 2: Summary of modern living habitat for *G. ruber*, *G. sacculifer*,
N. dutertrei, and *G. crassaformis* _____ 37

Table 3a: Similarity coefficients for planktonic foraminifera $\delta^{18}\text{O}$ results
during last 150 kyr _____ 43

Table 3b: Similarity coefficients for planktonic foraminifera $\delta^{18}\text{O}$ results
during MIS 3 _____ 43

Table 4: Planktonic foraminifer taxonomic categories _____ 47

Table 5: Background information of cores used in this study _____ 61

LIST OF FIGURES

Figure 1.1: Map of western tropical Pacific showing the location of Sulu Sea and IMAGES site MD97-2141 _____	6
Figure 1.2: Detailed bathymetric map of the Sulu Sea. _____	7
Figure 1.3: Average sea surface temperature and sea surface salinity in Indonesia and the western Pacific for April and October _____	9
Figure 2.1: Sulu Sea $\delta^{18}\text{O}$ record of <i>G. ruber</i> from ODP Site 769A and IMAGES core MD97-2141 _____	21
Figure 2.2: $\delta^{18}\text{O}_{G. ruber}$, $\delta^{18}\text{O}_{\text{seawater}}$, $\text{Mg}/\text{Ca}_{G. ruber}$ and average shell mass data from the Sulu Sea during the last 90 kyr _____	22
Figure 2.3: Comparison of isotopic records from Greenland and Antarctica to isotopic and trace element data from the Sulu Sea during the last 90 kyr _____	27
Figure 3.1: Map of location of the Sulu Sea and IMAGES core MD97-2141 _____	34
Figure 3.2: Vertical profiles of annual analyzed temperature and salinity across longitude 119.5° E transect _____	35
Figure 3.3: $\delta^{18}\text{O}$ records of <i>Globigerinoides ruber</i> , <i>Globigerinoides sacculifer</i> , <i>Neogloboquadrina dutertrei</i> and <i>Globorotalia crassaformis</i> during MIS 3 _____	42
Figure 3.4: Downcore variations in relative abundance of <i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. glutinata</i> , <i>G. bulloides</i> , <i>N. dutertrei</i> , <i>G. tumida</i> , <i>N. pachyderma</i> (r.), and <i>G. crassaformis</i> during MIS 3 _____	46
Figure 3.5: Time series of the relative abundance sums of “mixed layer” species and “thermocline” dwellers _____	46
Figure 3.6: Oxygen isotope “difference” curves _____	52
Figure 3.7: Comparison between Chinese loess magnetic susceptibility and Sulu Sea oxygen isotopic data. _____	53

Figure 4.1: $\delta^{18}\text{O}$ and SST estimates based on Mg/Ca in the Sulu Sea for the last 21,000 years _____	58
Figure 4.2: Map of core locations examined in his study _____	60
Figure 4.3: Compilation of sea-level data _____	63
Figure 4.4: Oxygen isotope and SST data versus age _____	65
Figure 4.5: Hypothetical thermocline reconstruction _____	68
Figure 4.6: Oxygen isotope, SST and $\delta^{18}\text{O}_{\text{seawater}}$ data versus age for cores where SST-based Mg/Ca measurements lead $\delta^{18}\text{O}$ _____	71
Figure 4.7: Water vapor concentration in the mid troposphere during January, 1989 _____	74
Figure 4.8: Global anomalies of precipitation associated with La Niña _____	75