LATE PLEISTOCENE NANNOFOSSIL ASSEMBLAGES AND TIME-AVERAGING IN THE FOSSIL RECORD [IODP SITE U1419]

An Undergraduate Research Scholars Thesis

by

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TABLE OF CONTENTS

Page

CHAPTER

ABSTRACT

Late Pleistocene Nannofossil Assemblages and Time-Averaging in the Fossil Record [IODP Site U1419] (May 2015)

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When looking at geologically rapid climatic changes, such as glacial/interglacial cycles, the true response of organisms may be obscured in the fossil record due to time averaging. Time averaging can also impact the rates of origination and speciation in the fossil record. Integrated Ocean Drilling Program (IODP) Site U1419 was cored in the Gulf of Alaska in 2013. It yielded a Late Pleistocene-Holocene sedimentary section with high sedimentation rates on the order of 1cm/year. The nannofossil assemblage at 1cm resolution across a glacial/interglacial boundary to determine (1) the yearly variability of the nannofossil assemblage and (2) changes in the nannofossil assemblage related to environmental forces across this transition. I will then use statistical methods to model how much variability in the assemblage would be lost due to time averaging on different time scales. The result of information loss due to time averaging could help to evaluate fossil records from areas with highly time averaged section.

DEDICATION

I would like to dedicate this paper and the hours of research behind it to the people who mean everything to me and have always encouraged me to follow my dreams: my parents.

ACKNOWLEDGMENTS

I would like to extend extraordinary gratitude to my advisor, Dr. Leah LeVay, for allowing me the opportunity to work on this project and for her consistent guidance and support along the way. I could not have achieved anything near this experience without your help.

I would also like to recognize the International Ocean Discovery Program for providing necessary resources for this study.

CHAPTER I

INTRODUCTION

Background

The fossil record is the infrastructure of modern geology. Specifically, records of a phytoplankton group, called nannofossils, aid the understanding of past environments and ecosystems, thus building on the knowledge of the present. The nannofossils that are found at Site U1419 are coccolithophores. Coccolithophores are marine unicellular phytoplankton that are composed of calcite plates that disaggregate after death into their individual constituent plates of 'armor' (Benton & Harper, 2009). Smaller organisms like these are often preserved better than larger ones, making coccolithophores and other nannofossils ideal subjects through which to examine the fossil record.

Nannofossils offer many unique advantages to both biostratigraphy and paleoceanography. Because they are widely distributed across oceans and evolve quickly, nannofossils are invaluable for use in biostratigraphy (Bown et al., 2004). These evolutionary events are well dated and correlatable across ocean basins. Additionally, nannofossils provide aid in paleoceanographic reconstructions. Different species display affinities to certain temperatures, salinities, light intensity and nutrient availability (Jordan and Chamberlain, 1997). Changes in the nannofossil assemblage can signal shifts in surface water conditions.

The fossil record, however, is far from a perfect model. The record itself depends on many factors that determine the preservation of organisms such as ocean chemistry and sedimentation rate (Kidwell, 1998). The greatest impedance of a clear chronological record is the time-averaging process. Time averaging describes the processes through which organisms from different periods of time come to be preserved together. A better understanding of this process may be gleaned from the original definition: a situation in which remains “accumulate from the local living community during the [relatively long] time required to deposit the containing sediment” (Walker and Bambach, 1971). Though disruption of sediment can lead to a time-averaged section, by far the most prevalent component of this process is the rate of sedimentation.

To study the effect of time averaging on the fossil record, I chose to examine microfossils from a location with high-sedimentation rates and little time averaging. Integrated Ocean Drilling Program (IODP) Site U1419 is located in the Gulf of Alaska and has sedimentation rates on the order of 1 cm/ yr (Jaeger et al., 2013; Figure 1). Because this geographic region is characterized by an extremely high rate of sedimentation, nannofossils can be sampled at a very high temporal resolution. This high rate of sedimentation translates to a death assemblage that is reflective of the life assemblage. Areas of high sedimentation rates in the open ocean are very rare and models that try to ‘fill in the gaps’ of time-averaged fossil assemblages are difficult to construct and prone to error (Backman, et. al., 2009).

Goals

The nannofossil assemblage in the sediment core was examined and quantified at 1cm resolution across the marine isotope stage (MIS) 2 to 3 glacial/interglacial transition (Figure 2) to determine two distinct results. First, the section was evaluated to determine the yearly variability of the nannofossil assemblage. Variability refers to the difference in the fossil assemblage between samples. Because time averaging removes data that would otherwise be available, it is expected that there will be higher variability in a high resolution sampling group than in a section that has been experimentally time-averaged to a lesser degree. The data was then statistically analyzed to determine how much of that variability was excluded from the fossil record in lower resolution regions. The core was also studied in order to determine changes in the nannofossil assemblage related to environmental forces across this transition zone. It is expected that with environmental changes, the fossil assemblages observed will change and adapt to the new conditions accordingly.

CHAPTER II

METHODS

Sampling

IODP Site U1419, drilled in the Gulf of Alaska in 2013 at a water depth of 721 meters, yielded a Late Pleistocene sedimentary section with an observable environmental transition. The sedimentation rates at this site are extremely high for the open ocean, on the order of 1cm/year (Jaeger et al., 2013). The lithology of the studied section is dark gray mud with clasts, which were sourced from the North American continent. In order to take full advantage of this project, a core displaying a high annual average sedimentation rate as well as an environmental transition was selected. Global oxygen isotope data from Lisiecki and Raymo (2005) as well as magnetic susceptibility data for Site U1419 were used to identify a one-meter interval of core that spans the MIS 2-3 boundary. During the formation of ice, oxygen isotope 16 (O^{16}) is preferentially used instead of O^{18} (Benton and Harper, 2009). This chemical tendency is what allows for the interpretation that a higher O^{18} to O^{16} ratio ($\delta^{18}O$) preserved in the sediments indicates colder, glacial conditions. Magnetic susceptibility is measured through an applied magnetic field and is a dimensionless proportionality constant that indicates the degree of magnetization of a material (Kukla, 1988). MIS's are defined by the global oxygen isotope curve and each stage is a separate glacial or interglacial period in Earth's paleoclimate. Four major MIS's are observed at Site U1419 as indicated by comparing the magnetic susceptibility record to the oxygen isotope curve of Lisiecki and Raymo (2005; Figure 2). It is important to note that at Site U1419, MIS 2 is expanded relative to MIS 1 and 3. This anomaly occurs because there was significant erosion of the St. Elias Mountain Range in Alaska during the MIS 2 glacial period (Jaeger at al., 2013).

Using the magnetic susceptibility data the MIS markers (Figure 2), it was established that the transition between MIS 2 and MIS 3 is between 82-83 meters beneath sea floor (mbsf).

Sample Preparation and Quantifying

Toothpick samples were taken from the archived core Section 341-U1419-10H-6A from 11cm to 111 cm. The core was sampled every centimeter along the meter-long interval, resulting in 100 samples. These samples were sealed in individual bags and stored until they were made into smear slides. The smear slides were made using the 'double slurry' method of Watkins and Bergen (2003). The sample was prepared on a glass cover slip. The sediment was worked with a toothpick in order to break up any clumps and then dried using a hot plate. Deionized water was added to re-suspend the sediment. The sediment was moved around with the toothpick to get a nice even spread. Once the sediment was evenly smeared across the slide; it was quickly place on the hot plate to dry. A small dab of Norland Optical Adhesive was placed on a glass microscope slide and the cover slip placed on top, sediment face- down. The slide was allowed to warm on the hot plate so that the adhesive fully spread out under the cover slip. The slides were then placed under a UV lamp for ~30 minutes or until the optical adhesive had cured. After all slides were made, the methodic identification and counting of the samples began.

Twenty smear slides were chosen randomly throughout the entire meter-long section. Abundance of nannofossils was observed and recorded based on the following four categories: barren, rare, few and common. The distinction of barren was made when < 1 nannofossils were observed within 10 fields of view. Rare samples were defined when <10 nannofossils were found in as many fields of view. The 'few' division was made based on if 10 nannofossils were observed within 10 fields of view. Finally, common samples contain >10 samples in as many fields of view. The first 300 fossils encountered in each of these slides were identified and recorded. Counts were performed on a Zeiss Axioscope at 1000x magnification. Identification of six individual species followed the careful process outlined in Figure 3. A focus group of ten consecutive slides at 1cm spacing was chosen to simulate a non-time averaged section of sediment. The first 100 fossils encountered were identified and recorded in this sampling group. The counts were then converted into percent abundances, which is the percentage of the assemblage a species makes up. Samples that were quantified contained the following six individual species: *Coccolithus braarudi, Coccolithus pelagicus, Cruciplacolithus neohelis, Gephyrocapsa muellerae, Gephyrocapsa* spp. >3 micron*, and Gephyrocapsa* spp. <3 micron (Figure 4). *Gephyrocapsa* spp. > 3 micron includes specimens that do not contain a distinctive bar across the central area of the specimen, which is the identifying feature for species of *Gephyrocapsa*.

Four sample groups were chosen for statistical analysis: Glacial, Interglacial, high resolution and low resolution. The glacial and interglacial groups consist of the data collected from those two respective environmental periods. This pairing of sample groups offers insight into environmental differences across the zone of transition. The high resolution group consists of ten spatially consecutive samples and represents a relatively complete fossil record that extends over a 10cm distance; all of these samples are within the MIS 3 interglacial. The low resolution group was assembled by selecting ten samples throughout the core, spaced approximately 10 cm apart and span both MIS intervals. These last two groups were chosen for the purpose of resolving the effects of sampling resolution on nannofossil assemblage trends. Mean, variance, and standard deviation was calculated for all four sampling groups. Variance is a statistical value used to express the spread that a certain data set exhibits and is represented by the following equation:

$$\sigma^2 = \frac{\Sigma X^2}{y}$$

Equation 1. –Variance σ=variance, y=number of means, X=means

CHAPTER III

RESULTS AND DISCUSSION

Overall nannofossil abundance data was recorded and graphed (Figure 5) for all 30 samples and graphed according to numbers that were assigned to the following abundances: barren, rare, few, and common (Table 3). Though the data represents a wide spread of results, a general trend does emerge: total nannofossil abundance during the interglacial period is greater than that of the glacial period (Figure 5). This trend seems to indicate environmental factors that effected abundance of calcareous phytoplankton; however, the same result could be caused because of geochemical differences that alter quality of preservation. In a second evaluation, percent abundances of each species were plotted with respect to meters below sea floor (Figure 6). A similar trend is apparent in these collections: higher abundances in the interglacial period than in the glacial period.

Results for statistical analysis of species abundance data are recorded in Table 4. The first pair of sampling groups was chosen in order to evaluate environmental changes across the glacial/interglacial transition. Comparing these first two sampling groups, variance values are higher within the interglacial period (Table 4, a). The exception to this trend is *Coccolithus braarudi*. Larger variance observed in the interglacial suggests an environment more productive to a wider range of nannofossils, a hypothesis supported by the study’s abundance evaluations. However, error is possible in this interpretation due to potentially fluctuating preservation quality across the MIS transition.

The same anomaly is observed in the appraisal of the latter two sampling groups as well (Table 4, b). These groups were chosen in order to resolve the effects of sampling resolution, or simulated time averaging, on nannofossil assemblage trends. The larger variance values in the high resolution group quantifies that the less time averaged sampling group shows a wider spread of data than the more time averaged group. This evidence supports the hypothesis that significant data is lost with higher degree of time averaging, or a lower sampling resolution. It possibility that environmental changes across the MIS 2-3 transition could influence the results of the sampling resolution experiment. However, because the 10 cm resolution data set spans both glacial and interglacial periods, if environmental change was contributing to the sampling resolution result, it would be expected to see a high variance in the 10cm data set that reflects the assemblage change across this transition.

CHAPTER IV

CONCLUSIONS

This study in Pleistocene age nannofossil assemblages was conceived with the goal of determining effects of environmental change and time averaging on the paleontological record. Results showed that the glacial/interglacial transition across MIS 2-3 did have an effect on nannofossil assemblages as did sampling resolution. In general, the samples from the interglacial MIS 3 show higher variance than samples from the glacial period. This could be due to either surface water changes or quality of preservation. The samples taken at 1cm resolution (Complete sample group) show higher variance than the samples taken at 10cm resolution (Time Averaged sample group. Variance as a statistical representation of data spread is useful in this case because it becomes clear that the true span of the data in the 1cm resolution is much wider than that of the 10cm resolution, supporting the hypothesis that variance is lost with time averaging. The environmental changes across the MIS 2-3 transition could influence the results of the sampling resolution experiment. However, because the 10 cm resolution data set spans both glacial and interglacial periods, if environmental change was contributing to the sampling resolution result, it would be expected to see a high variance in the 10cm data set that reflects the assemblage change across this transition. Tremendous expansion to this study is possible and would be desirable in order to provide more data with which to compare to this set of data. It would be interesting to examine the environmental implications of this project more carefully. Individual nannofossil species have affinities for differing amounts of temperature, salinity, nutrients, etc. With more time and data these differences could be quantified and a reconstruction of the environmental transition could be produced. Also, an extension of this study could investigate possible ways to handle time averaging. Some paleontologists have argued that time averaging can be useful in filtering out short-term variations in paleoenvironmetnt (Olszewski, 1999). While this may be true, the erosive impact that time averaging has on the fossil record is undeniable. This study successfully concludes that sampling resolution does, in fact, influence paleontological records, which could have substantial implications for paleontological studies.

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APPENDIX

Figures

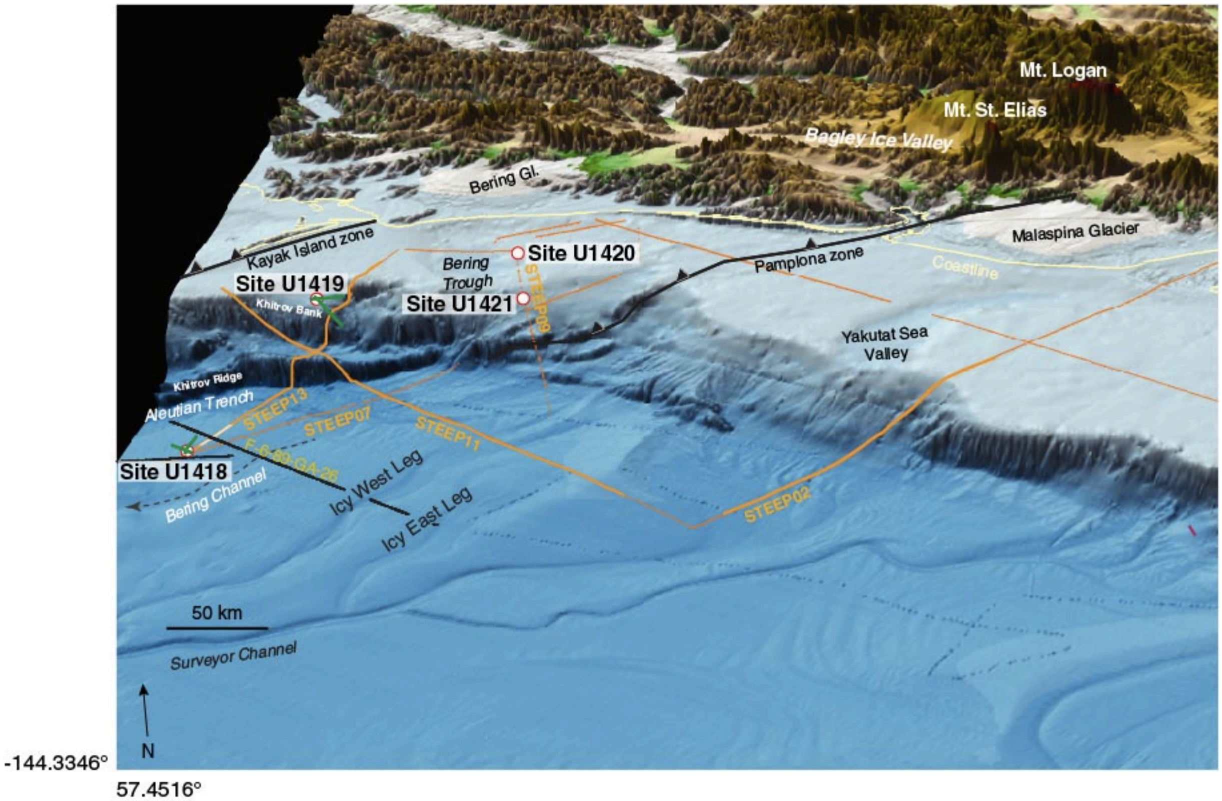

Figure 1.—Site U1419 Location of IODP Site U1419 in the Gulf of Alaska

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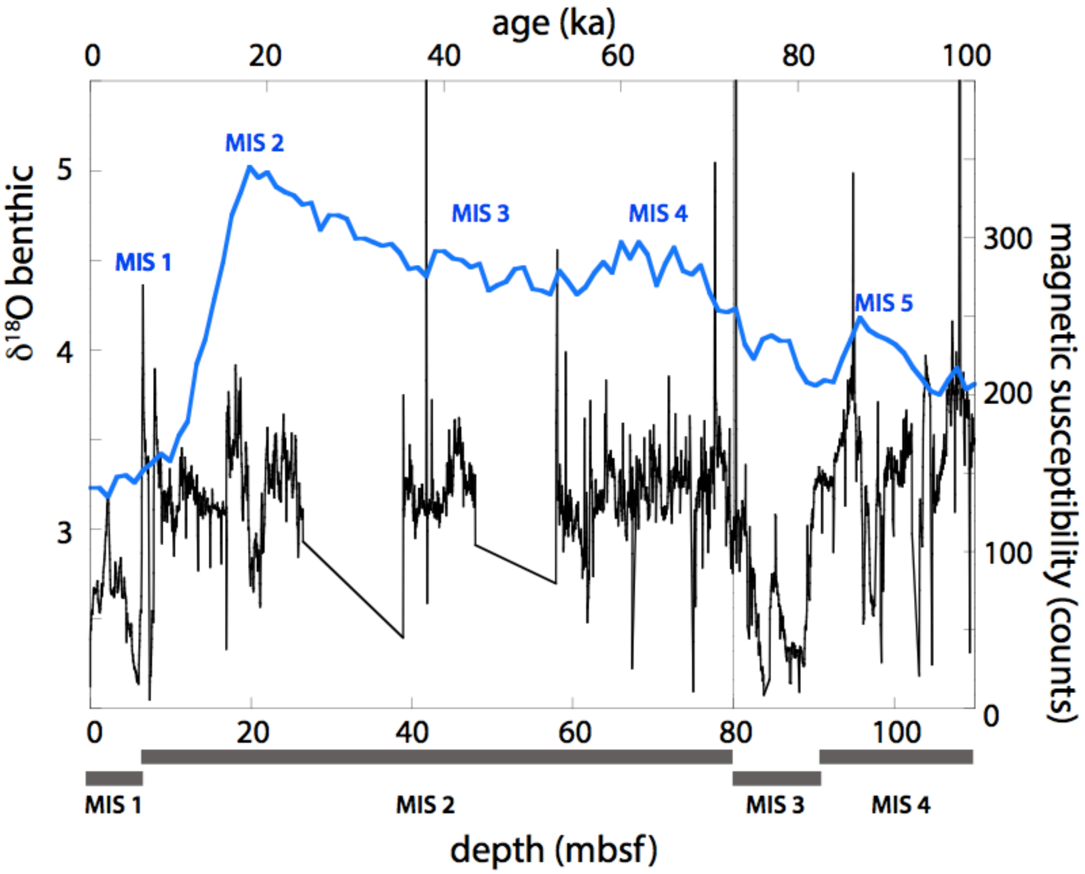


Figure 2. –MIS Marine Isotope Stages plotted on two separate data sets: magnetic susceptibility from Site U1419 and global oxygen isotope data.

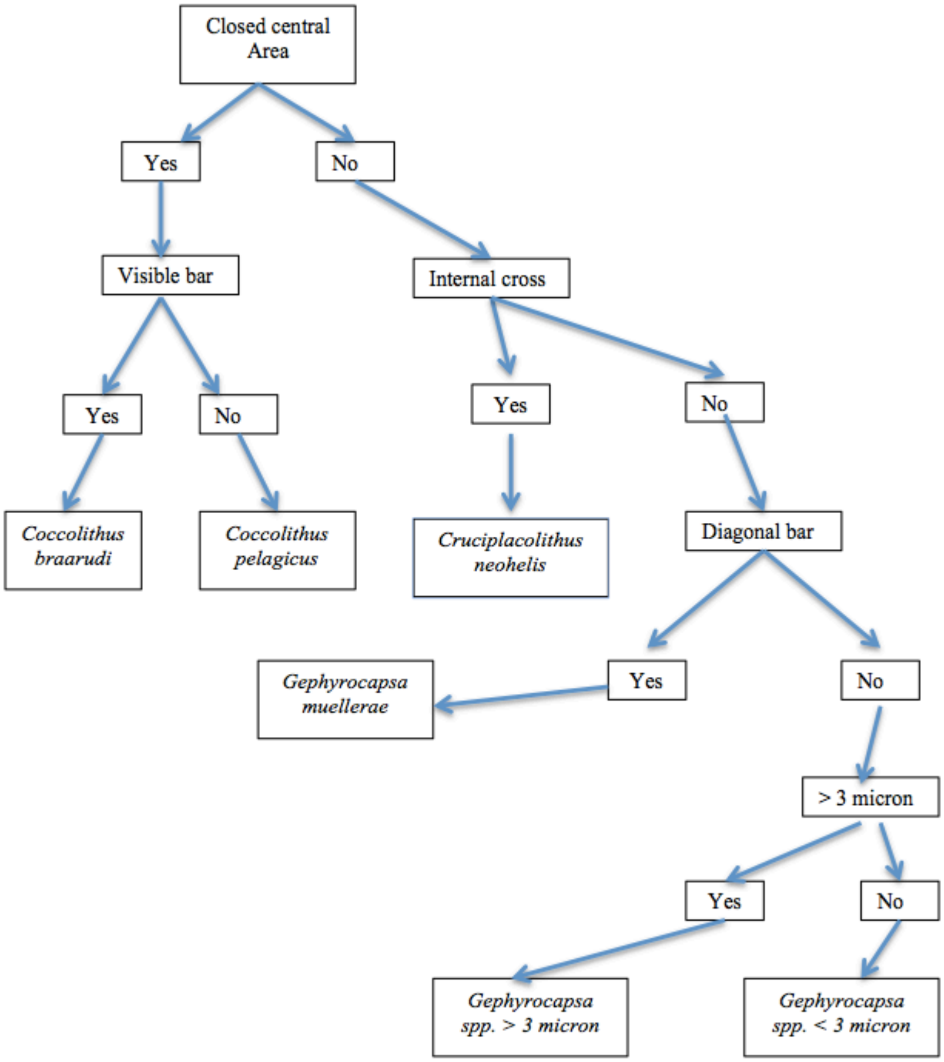


Figure 3.—Nannofossil Classification Flowchart outlining the structural differences used to differentiate between the nannofossil species listed in figure 3.

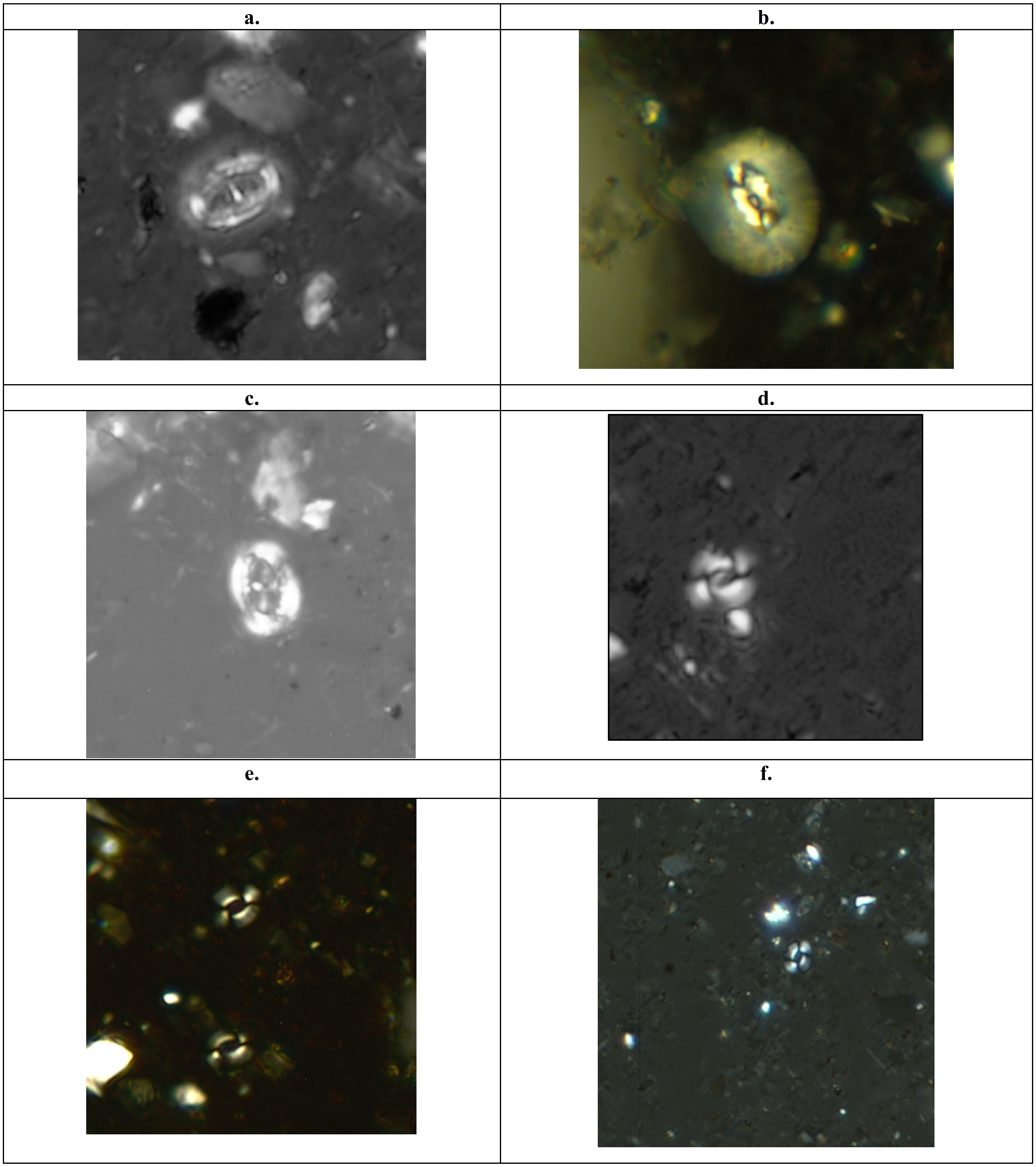


Figure 4.—Nannofossil Species (a.) *Coccolithus braarudi*, (b.) *Coccolithus pelagicus*, (c.) *Cruciplacolithus neohelis*, (d.) *Gephyrocapsa muellerae*, (e.) *Gephyrocapsa spp. > 3 micron*, (f.) *Gephyrocapsa spp. < 3 micron*.

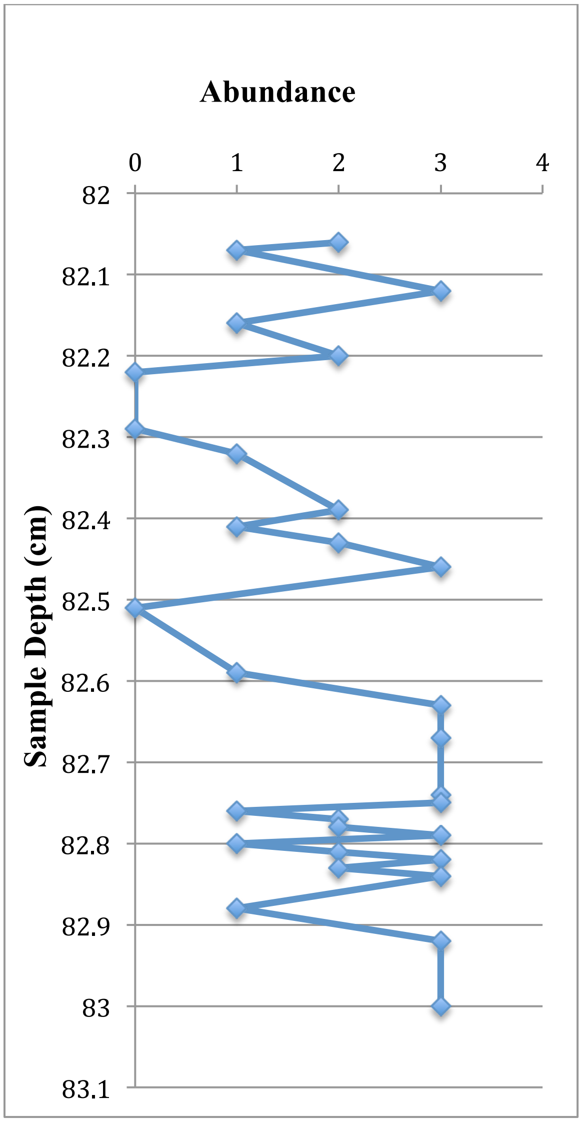


Figure 5.—Abundance Overall abundance graph of nannofossils.

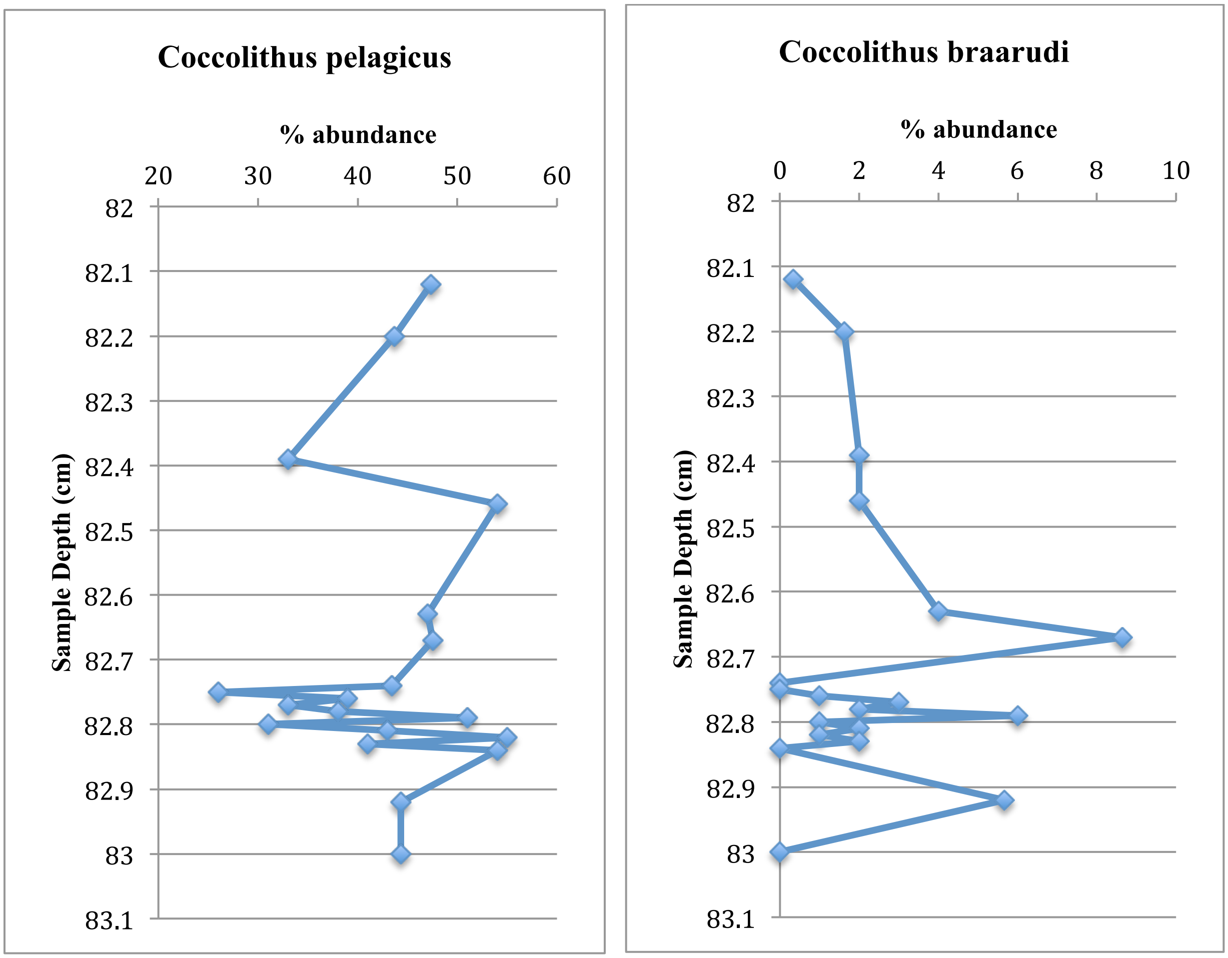
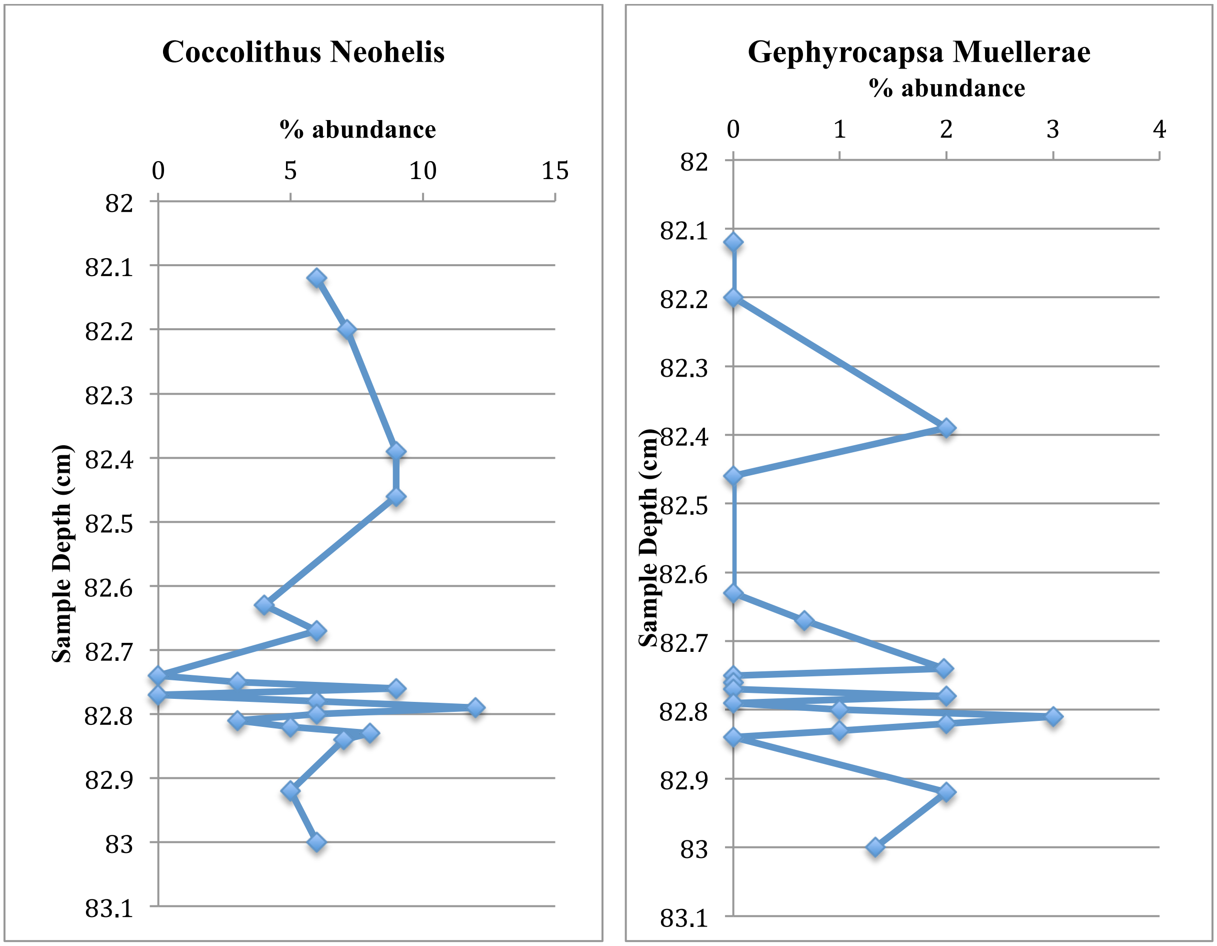


Figure 6.—Percent Abundance Percent abundances of the six individual nannofossil species featured in the study


Coccolithus Neohelis

Gephyrocapsa Muellerae

Figure 6. Continued.

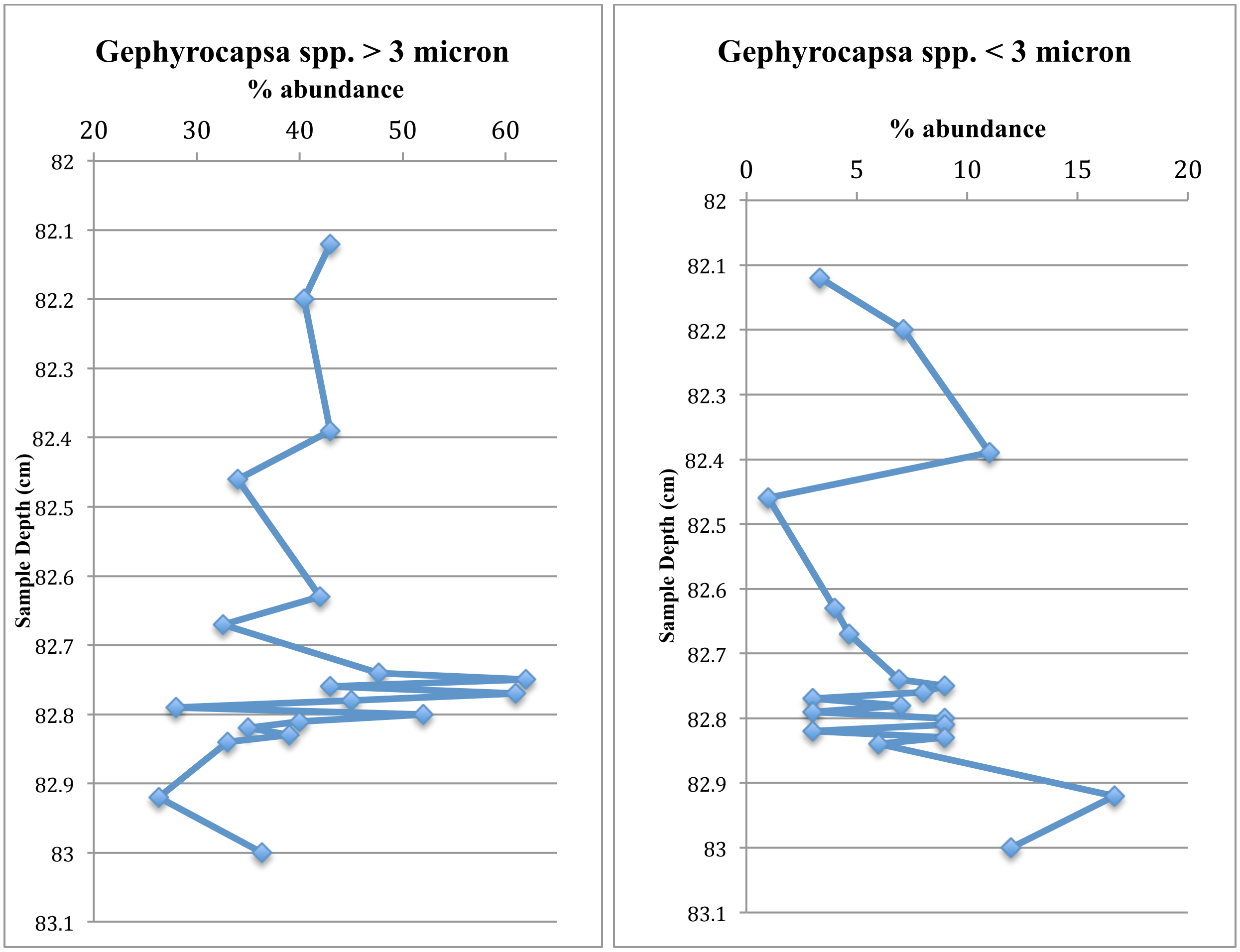


Figure 6. Continued.

Tables

mbsf	82.06	82.07	82.12	82.16	82.2
sample	11	12	17	21	25
abundance	F	R	C	R	F
C. braarudi			1		
C. pelagicus			142		
C. neohelis			18		
G. muellerae			0		
G. spp.>3um			129		
G. spp.<3um			10		
total			300		

mbsf	82.22	82.29	82.32	82.39	82.41
sample	27	34	37	44	46
abundance	B	B	R	F	R
C. braarudi				2	
C. pelagicus				33	
C. neohelis				9	
G. muellerae				2	
G. spp.>3um				43	
G. spp.<3um				11	
total				100	

mbsf	82.41	82.43	82.46	82.51	82.59
sample	46	48	51	56	64
abundance	R	F	C	B	R
C. braarudi			2		
C. pelagicus			54		
C. neohelis			9		
G. muellerae			0		
G. spp.>3um			34		
G. spp.<3um			1		
total			100		

Table 1.—Raw Nannofossil Counts

mbsf	82.63	82.67	82.74	82.75	82.76
sample	68	72	79	80	81
abundance	C	C	C	C	R
C. braarudi	4	26	0	0	1
C. pelagicus	47	143	132	26	39
C. neohelis	4	18	0	3	9
G. muellerae	0	2	6	0	0
G. spp.>3um	42	98	145	62	43
G. spp.<3um	4	14	21	9	8
total	100	301	304	100	100

mbsf	82.77	82.78	82.79	82.8	82.81
sample	82	83	84	85	86
abundance	F	F	C	R	F
C. braarudi	3	2	6	1	2
C. pelagicus	33	38	51	31	43
C. neohelis	0	6	12	6	3
G. muellerae	0	2	0	1	3
G. spp.>3um	61	45	28	52	40
G. spp.<3um	2	7	3	9	9
total	100	100	100	100	100

mbsf	82.82	82.83	82.84	82.88	82.92	83
sample	87	88	89	93	97	105
abundance	C	F	C	R	F	F
C. braarudi	1	2	0		17	0
C. pelagicus	55	41	54		133	133
C. neohelis	5	8	7		15	18
G. muellerae	2	1	0		6	4
G. spp.>3um	35	39	33		79	109
G. spp.<3um	3	9	6		50	36
total	100	100	100		300	300

Table 1. Continued.

mbsf	sample	C. braarudi	C. pelagicus	C. neohelis	G. muellerae	G. spp.> 3um	G. spp.<3um
82.12	17.00	0.33	47.33	6.00	0.00	43.00	3.33
82.20	25.00	1.62	43.69	7.12	0.00	40.45	7.12
82.39	44.00	2.00	33.00	9.00	2.00	43.00	11.00
82.46	51.00	2.00	54.00	9.00	0.00	34.00	1.00
82.63	68.00	4.00	47.00	4.00	0.00	42.00	4.00
82.67	72.00	8.64	47.51	5.98	0.66	32.56	4.65
82.74	79.00	0.00	43.42	0.00	1.97	47.70	6.91
82.75	80.00	0.00	26.00	3.00	0.00	62.00	9.00
82.76	81.00	1.00	39.00	9.00	0.00	43.00	8.00
82.77	82.00	3.00	33.00	0.00	0.00	61.00	3.00
82.78	83.00	2.00	38.00	6.00	2.00	45.00	7.00
82.79	84.00	6.00	51.00	12.00	0.00	28.00	3.00
82.80	85.00	1.00	31.00	6.00	1.00	52.00	9.00
82.81	86.00	2.00	43.00	3.00	3.00	40.00	9.00
82.82	87.00	1.00	55.00	5.00	2.00	35.00	3.00
82.83	88.00	2.00	41.00	8.00	1.00	39.00	9.00
82.84	89.00	0.00	54.00	7.00	0.00	33.00	6.00
82.92	97.00	5.67	44.33	5.00	2.00	26.33	16.67
83.00	105.00	0.00	44.33	6.00	1.33	36.33	12.00

Table 2.—Normalized Nannofossil Counts Normalized counts of nannofossils observed

Nannofossil Abundance	
Barren	0
Rare	1
Few	2
Common	3

Table 3.—Overall Abundance number coding for all 30 samples that were observed in the microscope

a.

		C. braarudi	C. pelagicus	C. neohelis	G. muellerae	G. spp.>3µ	G. spp.<3µ
Glacial	mean	3.10	45.42	6.85	0.44	39.17	5.18
	variance	7.29	40.23	3.15	0.54	18.24	10.03
	st. dev.	2.70	6.34	1.78	0.74	4.72	3.17
Interglacial	mean	1.82	41.78	5.38	1.10	42.18	7.81
	variance	3.77	68.56	10.54	0.99	116.89	13.53
	st. dev.	1.94	8.28	3.25	1.00	10.81	3.68

b.

		C.braarudi	C.pelagicus	C.neohelis	G.muellerae	G.spp.>3µ	G.spp.<3µ
High resolution	mean	1.80	41.10	5.90	0.90	43.80	6.60
	variance	2.76	87.55	10.76	1.13	120.38	7.90
	st. dev.	1.66	9.36	3.28	1.06	10.97	2.81
Low resolution	mean	2.70	44.96	5.79	0.89	38.38	7.41
	variance	7.24	28.57	5.38	0.54	47.24	17.44
	st. dev.	2.69	5.35	2.32	0.73	6.87	4.18

Table 4.—Statistical Results Mean, variance, and standard variation of the four chosen sample groups.